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RAPID SCREENING OF DECISION OPTIONS

DECISIONS AND DESIGNS, INCORPORATED
McLEAN, VIRGINIA

OCTOBER 1976

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Judith Selvidge

ADVANCED ARPA
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PROGRAM

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TECHNICAL REPORT 76-12

RAPID SCREENING OF DECISION OPTIONS

by

Judith Selvidge

Sponsored by

Defense Advanced Research Projects Agency
Contract N00014-76-C-0074

October, 1976

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SUMMARY

Decision analysis is a formal method for dealing with decision making under uncertainty that takes into account the decision maker's many options, the possible uncertain events that may occur, the probabilities of occurrence of various outcomes of these events, and the decision maker's utility or value for consequences of different combinations of options and outcomes. By means of the format of decision trees or diagrams, the decision situation can be presented graphically and, in particular, the possible decisions and events clearly enumerated and the sequential nature of the decision process shown. Such a full description of the decision situation, however, may be so complex and its resolution so time-consuming that the analysis is not attempted at all.

In this paper we discuss a method, applicable to some decision problems, for reducing the analysis to a small, rather manageable set of options and a limited number of uncertain outcomes. We call this technique "rapid screening of decision options." This technique makes it possible to analyze decision problems on a small, desk-top computer (the IBM 5100). The decision maker specifies the structure of the problem by listing the decision options, the outcomes of the uncertain events, and the dimensions along which the value of the consequences of options and outcomes will be measured. The decision maker then assesses probabilities of occurrence for different outcomes, the desirability of each consequence along each value dimension, and the relative importance of each of these value dimensions. This information becomes the input to the computer program. The output of the computer program is a summary measure of the expected value for each option. By adjusting the various inputs to the computer program, the decision maker can then test the sensitivity of these expected values for the different options to various assumptions, for example, assumptions such as the probabilities of the outcomes and the weights of different dimensions of values for the consequences.

This evaluation procedure provides a way for decision makers to study a set of options in an approximate fashion when a rapid analysis is necessary either to identify areas for further detailed study or to support a decision that must be made immediately. The procedure can also be used before a problem arises for contingency planning. The rapid screening technique is illustrated here by means of two examples which describe decision situations of interest to military decision makers.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Decision analysis is a formal method for dealing with decision making under uncertainty that takes into account the decision maker's many options, the possible uncertain events that may occur, the probabilities of occurrence of various outcomes of these events, and the decision maker's utility or value for consequences of different combinations of options and outcomes. By means of the format of decision trees or diagrams, the decision situation can be presented graphically and, in particular, the possible

decisions and events clearly enumerated and the sequential nature of the decision process shown. Such a full description of the decision situation, however, may be so complex and its resolution so time-consuming that the analysis is not attempted at all.

In this paper we discuss a method, applicable to some decision problems, for reducing the analysis to a small, rather manageable set of simple options and a limited number of uncertain outcomes. We call this technique "rapid screening of decision options." In order to apply this technique, the problem must be stated so that only one main decision is considered. The main decision involves selecting an action from among a set of several options. A second requirement for the use of this method is that only one main uncertain event be considered. The uncertain event has a number of different possible outcomes for which probabilities are assessed. Which of the outcomes of the uncertain event will actually occur is not known until after the decision is taken. Whenever possible, the uncertain event is defined so that the probabilities of occurrence of its different outcomes are independent of the option taken.

This evaluation procedure provides a way for decision makers to study a set of options in an approximate fashion when a rapid analysis is necessary either to identify areas for further detailed study or to support a decision that must be made immediately. The procedure can also be used before a problem arises for contingency planning. The rapid screening technique is illustrated here by means of two examples which describe decision situations of interest to military decision makers.

CONTENTS

FIGURES

TABLES

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This research was supported by the Defense Advanced Research Projects Agency and monitored by the Office of Naval Research under contract N00014-76-C-0074.

The examples discussed in this paper are based on work carried out by Drs. C. W. Kelly, III and C. R. Peterson of Decisions and Designs, Incorporated (DDI) for presentation to military decision makers. The computer software was developed by Mr. J. J. Allen, Jr. of DDI.

RAPID SCREENING OF DECISION OPTIONS

1.0 INTRODUCTION

A manager faced with a complex decision involving many options, uncertainties about future events, and consequences whose values can be measured in a number of different ways, may use techniques of decision analysis to choose the best alternative action among various different options. "Decision analysis" is the name given to a recently developed, formal procedure for resolving such decision problems where the decision maker must choose from among a number of options and where the best decision depends in part on some uncertain future events whose outcomes can only be guessed at when the decision is made.[1] The techniques of decision-analytic procedure help the decision maker to enumerate all the possible acts (called the decision options) and all the relevant uncertain events with their different possible outcomes. The procedure also requires that the decision maker express in numerical terms both his feelings about the relative likelihood (called the probabilities) of different outcomes of the uncertain events and about the desirability (called the value or utility) of the consequences of different outcomes in conjunction with the different possible decision options. Once the decision problem has been described in this fashion, the decision-analytic procedure specifies the way in which this numerical information can be aggregated into summary figures (one for each decision option) which the decision maker can use as an indicator of the best decision option.

The description of a decision problem in the decision-analytic procedure is generally presented in the form of a decision diagram, called a "decision tree," as shown in Figure 1-1. In this format, decision points (called nodes) are represented by small squares with the different possible options shown as lines or paths coming out of the square. Points or nodes where uncertain events will occur are represented by small circles with lines extending out to indicate the different possible outcomes of the event. One function of the decision tree is to illustrate how the decision problem unfolds over time. The decision and event nodes are arranged sequentially in the order in which decisions must be made and in which outcomes of the uncertain events are

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[1]Two good presentations of decision analysis are: Howard Raiffa, Decision Analysis: Introductory Lectures on Choices Under Uncertainty (Reading, Mass.: Addison-Wesley, 1968); and Rex V. Brown, Andrew S. Kahr, and Cameron R. Peterson, Decision Analysis for the Manager (New York: Holt, Rinehart, and Winston, 1974).

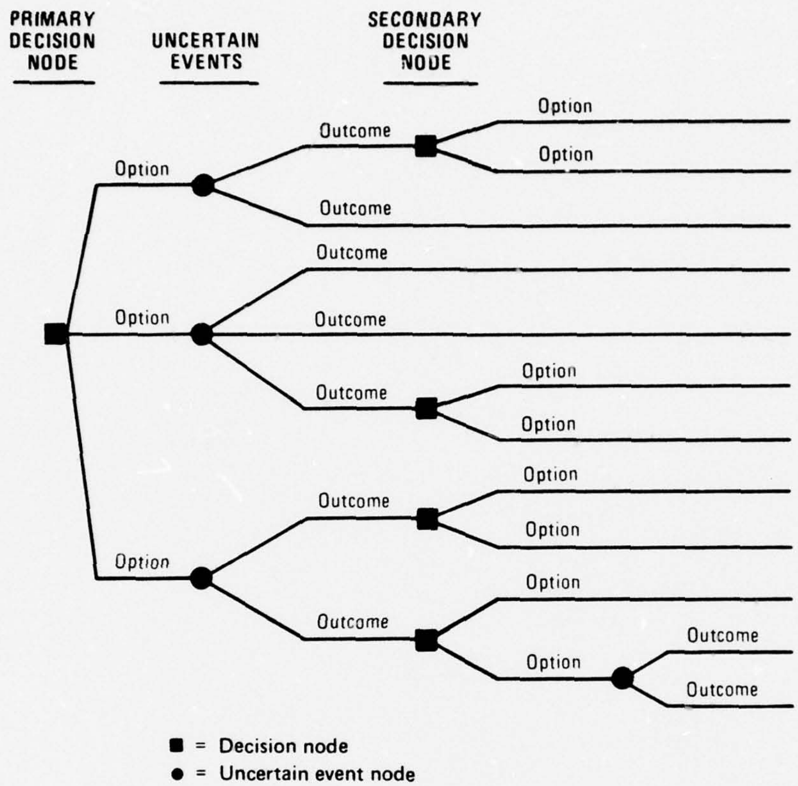

Figure 1-1

A SCHEMATIC OF THE DECISION TREE FORMAT

revealed to the decision maker. This sequential format helps the decision maker to keep track of the dependencies between events and decisions and facilitates the recording of various costs and benefits where they occur in the decision process. Each different path all the way through the tree from the beginning to some endpoint represents a possible combination of decision options and event outcomes. This format also facilitates calculations that allow the decision maker to decide in advance whether or not it is worthwhile to collect additional information at various stages in the process in order to reduce the subsequent uncertainty.

Typically, when decision analysis is applied to real or realistic problems, extensive use is made of the decision tree format in order to describe fully the problem. Two drawbacks of this complete formulation of a problem, however, are that the procedure can be quite time-consuming and that new users of the method often find the presentation of a real problem in the form of a complex tree to be confusing. Furthermore, the decision tree format does not provide a convenient way for recording the costs and benefits when these need to be measured simultaneously in terms of a number of different factors (e.g., dollars, human lives, military advantage, political implications).

In this paper, a method is presented for the rapid, numerical evaluation of decision options by means of a version of decision analysis which follows standard decision-analytic procedure except that the decision tree is replaced by a basic matrix format.[2] In order to use basic matrices to replace the tree, however, the essence of the decision problem must be captured by a description which includes only a single major decision point and only one important uncertain event. In addition, the probabilities of occurrence of the different outcomes of the uncertain event should be independent of the decision options; that is, the probabilities should not change for different decision options. Some decision problems are naturally of this basic form; some others can be simplified to conform to the basic description by eliminating some of the detail from a complete problem description. For decision problems described in this way, the rapid screening procedure is a short-cut method for obtaining many of the benefits of a decision analysis without carrying out a full sequential decision analysis. The procedure is a quick and useful way of studying a reasonable approximation of a particular decision:

- To expedite analysis when time for it is very short,

- To identify critical options or features of the problem for more complete analysis, and

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[2]Appendix A contains a detailed discussion of these alternative ways of presenting a decision problem.

- o To introduce users to the concepts and procedures of decision analysis in a simple but realistic setting.[3]

The three basic steps in the rapid screening of decision options are as follows: First, the options to be considered are selected, and the uncertain event of interest is described. Second, the value of each of these options is determined in an approximate fashion. In the evaluation, the decision maker takes explicit account of the probabilities of different outcomes of the uncertain event and the costs and benefits of all combinations of options and possible outcomes. This information is processed mathematically and summarized for each option as a single expected value. Finally, the sensitivity of the results of the analysis to changes in the input values (the probabilities, the costs, and the benefits) is tested.

The evaluation is carried out by using a flexible, interactive computer program called "OPINT" on a small desk-top sized portable computer (the IBM 5100 which has 64K bytes of memory and an APL interpreter). The computer software and the operation of the program are described in a user's manual developed while this report was prepared.[4]

The rapid evaluation technique is both presented in abstract terms and applied to the hypothetical example of the mobilization decision faced by a NATO commander who receives information indicating the Warsaw Pact forces may be preparing to attack NATO countries. Another hypothetical example, one concerned with a naval evacuation of civilians, is also cited to illustrate refinements of the rapid-screening technique.

Removing some of the complexity and detail (which would be preserved by the decision tree format) of a problem

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[3] For readers experienced in the use of decision trees, two other advantages of this basic matrix formulation can be mentioned:

1. The matrix form facilitates the use of "regret" as a measure of the value for difficult-to-quantify factors; and
2. The restriction on the probabilities (independence from the options) permits a simple graphical analysis (and presentation) of the sensitivity of the decision to change in the probabilities.

[4] J.J. Allen et al., Computer-Assisted Options Screening and Intelligence Assessment: Software User's Guide (McLean, Va.: Decisions and Designs, Inc., October, 1976). The description of OPINT and its capabilities reflects an earlier version of the software than that described in the current user's guide.

description to fit the requirements of the basic matrix format entails a loss of information. In each application of the method, the decision maker must judge whether the simplifications which allow for a rapid screening are so restrictive as to invalidate the results of the analysis. The two examples used here to illustrate the method have been presented to groups of military decision makers. The concensus of these decision makers has been that the resulting simplified problems are still sufficiently realistic to serve their purposes.

The primary advantage of the simplification is that it makes possible a systematic, numerical evaluation of a problem which, because of limited time, might never be analyzed by the more time-consuming decision tree method.

2.0 STRUCTURING THE DECISION PROBLEM

As a first step in this procedure for rapid screening of decision options, the user (who may be the decision maker or may be a member of the decision maker's staff) describes the problem structure by specifying the decision options, the uncertain event and its possible outcomes, and the factors to be considered in evaluating the desirability of the consequences of different option-outcome combinations.

2.1 Decision Options

In listing the options to be evaluated, the user should be careful to begin by considering all plausible options. Next, the user selects from this complete list a restricted number of options representing the serious contenders for choice, for inclusion in the evaluation. The number of options actually evaluated is restricted in order to save time. As will be seen in the later sections, the time needed to assess the numerical inputs to the evaluation increases greatly as the number of options increases. Generating options and selecting those for further analysis, however, is a crucial part of the analysis since the decision analysis cannot identify the best overall decision if that decision is not among the options considered. Research into how best to generate and restrict the decision options is currently underway.

The options selected for analysis must also be compatible with the requirements of this simplified model, or description of the problem, namely, all the options must be available for choice at the same time. An option which says, "Do A and, then, depending upon the outcome (which will be known later) of an uncertain event X, do either B or C," is not allowed. On the other hand, the options "Do nothing" or "Maintain the status quo" are legitimate.

2.2 The Uncertain Event

The uncertain event of interest in the decision problem is that future event whose resolution or particular outcome cannot now be predicted with certainty, but whose particular outcome, if it were known, would allow the decision maker to say for sure what option should be taken. The uncertain event can be a state of nature (such as an earthquake or some meteorological condition) which no one can control, or it may simply be someone else's decision option which is beyond the control of the person doing the decision analysis (such as a governmental policy change or the action of an enemy). The requirement of the simplified decision model which must be met here is that the probabilities of the

different possible outcomes of the uncertain event be independent of the decision options. This independence means that the probabilities must not change as a function of the decision option chosen. For uncertain events which are states of nature, this condition is met. For example, whether or not an earthquake occurs in San Francisco next year does not depend on whether or not you decide to move there. When the uncertain event is someone else's decision, however, the necessary independence may or may not be a reasonable assumption. Sometimes the dependence may be ignored if the user believes it causes only a small change in the probabilities from option to option. Sometimes the event can be restated in a way that removes or reduces the dependence.

2.3 Basic Matrix Format

A decision problem whose decision options and uncertain events are formulated as described above can be represented as the decision tree shown in Figure 2-1. However, since

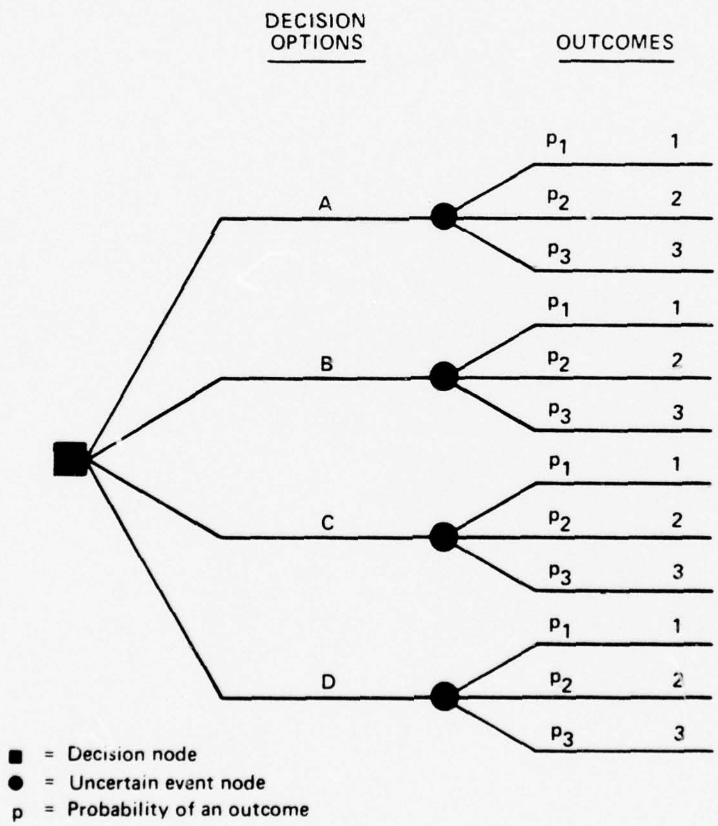

Figure 2-1

AN EXAMPLE OF THE SIMPLIFIED DECISION PROBLEM WITH FOUR DECISION OPTIONS AND THREE EVENT OUTCOMES REPRESENTED BY A DECISION TREE

there is only one decision node and one uncertain event of interest, an alternative way of displaying this information is in the form of a table or matrix.[1] Down the side of the matrix, there is a row for every decision option. Across the top of the matrix each possible outcome of the uncertain event is represented by a column. Each cell in the matrix represents a combination of a particular decision option and an outcome of the event, and, therefore, each cell corresponds to a path through the decision tree. The cells of the matrix will contain the value, on some dimension, of the combination of the corresponding option and outcome. A matrix is prepared for each of the dimensions of value to be considered. Table 2-1 shows the basic matrix obtained by converting the example of Figure 2-1 to the matrix format.

Uncertain Event

Outcomes

Decision Options		1	2	3
	A			
	B			
	C			
	D			

Probabilities for the Uncertain Event

Outcomes

1	2	3	
P_1	P_2	P_3	Total: 1.00

Table 2-1 – AN EXAMPLE OF THE DECISION PROBLEM PRESENTED IN THE BASIC MATRIX FORM WITH FOUR DECISION OPTIONS AND THREE EVENT OUTCOMES

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[1] Many statistical texts introduce the concepts of decision theory by presenting elementary decision problems in matrix form (the "payoff table" or "opportunity loss" table). The commonly used example is the decision to carry or not to carry an umbrella, given uncertainty about the event "rain" or "no rain."

The probabilities associated with the different outcomes of the uncertain event can also be presented in this tabular form and are later shown at the bottom of Figure 2-2. Only one row is needed since the event has been defined so that its outcome probabilities do not change for different decision options.

Many people find that problems are easier to understand when expressed in this matrix format rather than the decision tree form. The matrix format is also a bit easier to display on the cathode ray tube of a computer.

2.4 Warsaw Pact Attack Example

The first step in the rapid evaluation of decision options, namely, describing the decision problem in a simplified format, has been explained in abstract terms. The following example provides a more concrete application of this format. The problem analyzed is one which might be faced by a NATO decision maker.

Suppose that intelligence information indicates that there is a build-up of Warsaw Pact forces in Eastern Europe and the Western USSR. The uncertain event of interest is whether or not these forces will invade NATO countries. The decision to be made is: What alert posture should NATO assume? The decision about the extent of the alert must be made before the intentions of the Warsaw Pact forces are known for certain. If the NATO commander is considering four alternative levels of alert: Maintain status quo, military vigilance, simple alert, and reinforced alert, then the decision problem can be structured in the simplified decision-tree format shown in Figure 2-2.

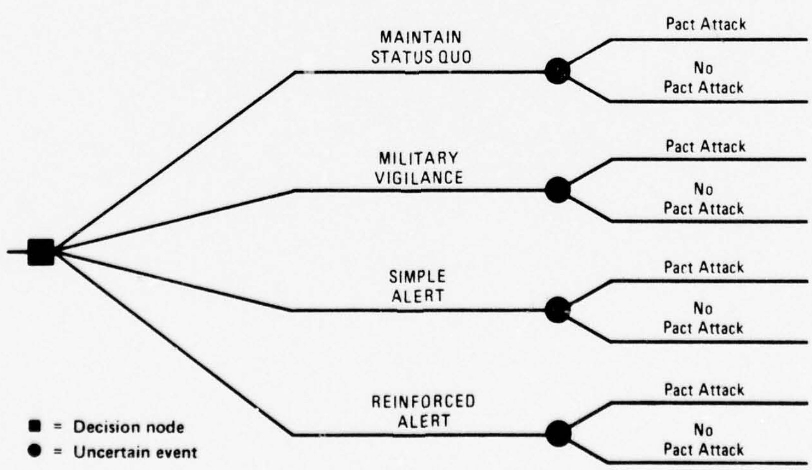

Figure 2-2
WARSAW PACT ATTACK EXAMPLE – SIMPLIFIED FORMAT

In matrix form, this decision problem has the rows and columns shown in Table 2-2.

VALUE MATRIX

Decision Options	Uncertain Event: Is an Attack Planned?	
	OUTCOMES	
	Pact Attack	No Pact Attack
Maintain Status Quo		
Military Vigilance		
Simple Alert		
Reinforced Alert		

PROBABILITIES

Pact Attack	No Pact Attack

Table 2-2 — WARSAW PACT ATTACK EXAMPLE IN MATRIX FORM

The uncertain event has been defined as whether or not the Warsaw Pact forces are planning to attack. The simplifying assumption is made that the intention of the Warsaw Pact forces does not depend on whether the NATO forces maintain or increase their level of alert. Therefore, the probabilities of attack and no attack need to be estimated only once and will not change after the NATO decision maker selects among the decision options.

2.5 Value Structure

The final step in structuring a decision problem is to identify the important factors that describe the possible consequences of outcomes and options and to determine how happy or unhappy the decision maker expects to be with a particular decision. These factors are the dimensions on which the decision maker's satisfaction with different combinations of options and outcomes is measured. For some problems, a great many descriptors can be applied to the consequences. In that case, the analyst should restrict consideration to the factors of primary importance. By definition, there cannot be too many of these. Often fewer than a half dozen factors are sufficient to describe the consequences. The consequences of many business decisions, for example, can be described simply in monetary terms. For social and military decision making, however, factors such as "political implications" or "lives lost" may be important. Besides selecting these important factors from among the many possible, the decision maker must also assign an "importance weight" to each factor. These weights indicate relative importance among the different factors and are used to combine ratings on each of the different dimensions into a single summary measure of the value. In the Warsaw Pact attack example, a military operations expert described in some detail what activities would be entailed in each of the options (maintaining the status quo through reinforced vigilance) and what the probable consequences of these activities would be both for the case of a Pact attack and for no Pact attack. After listing these consequences, the military expert concluded that they could be grouped into three general categories:

- <u>Alert Cost</u> (e.g., cost of deploying additional forces, assuming control of civilian transportation);
- <u>Political Cost</u> (e.g., embarrassment of being wrong if NATO forces prepare for an attack which never materializes); and
- <u>Military Risk</u> (e.g., expected military loss--lives, equipment, territory, etc.--if the attack occurs and NATO is unprepared).

These categories become the value dimensions of interest. To fill the value matrices, three basic matrices are set up, each representing one of the value dimensions. Each option and event outcome combination is rated on each of these dimensions. Then a fourth matrix, the "combination valuation," which is the weighted sum of the measures in each of three categories, is formed.

2.6 Computer Aid

The main contributions of the computer as an aid in the rapid scanning of decision options are (1) in carrying out the calculations of the expected value of different options once the component probabilities, values, and weights have been specified, and (2) in repeating the calculations many times to test (at the direction of the user) the effect of changes in the inputs. However, the OPINT computer program also acts as a recording device, as the decision problem is structured, by keeping track of and displaying the lists of options, outcomes, and value dimensions. The analyst or user types the problem description into the computer in response to questions posed by the computer program and displayed on a cathode ray screen. Figure 2-3 shows the steps followed in describing the Warsaw Pact attack decision problem in this way. Successive questions are posed by the computer; the user's responses are underlined.

```
NUMBER OF DIMENSIONS OF VALUE TO BE CONSIDERED: 3
NUMBER OF ACTIONS: 4
NUMBER OF STATES: 2
 3 VALUE MEASURES -  4 ACTIONS -  2 STATES
IF THESE VALUES ARE CORRECT TYPE GO: GO
ENTER THE STATE LABELS TO BE USED:
ENTER LABELS ONE PER LINE  5 CHARACTERS PER LINE.
WHEN COMPLETED HIT THE EXECUTE KEY.
LABEL [ 1]: [ATTCK]
LABEL [ 2]: [NOATK]
LABEL [ 3]: [     ]
THE LABELS YOU HAVE ENTERED ARE:
 1-ATTCK
 2-NOATK
IF THESE VALUES ARE CORRECT TYPE GO: GO
ENTER THE ACTION LABELS TO BE USED:
ENTER LABELS ONE PER LINE  8 CHARACTERS PER LINE.
WHEN COMPLETED HIT THE EXECUTE KEY.
LABEL [ 1]: [MAINTAIN]
LABEL [ 2]: [MIL.VIG.]
LABEL [ 3]: [SIMPLE  ]
LABEL [ 4]: [REINFRCD]
LABEL [ 5]: [        ]
THE LABELS YOU HAVE ENTERED ARE:
 1-MAINTAIN
 2-MIL.VIG.
 3-SIMPLE
 4-REINFRCD
IF THESE VALUES ARE CORRECT TYPE GO: GO
ENTER THE TITLES FOR EACH OF THE DIMENSIONS OF VALUE.
ENTER LABELS ONE PER LINE 20 CHARACTERS PER LINE.
WHEN COMPLETED HIT THE EXECUTE KEY.
LABEL [ 1]: [ALERT COST          ]
LABEL [ 2]: [POLITICAL COST      ]
LABEL [ 3]: [MILITARY RISK       ]
LABEL [ 4]: [                    ]
THE LABELS YOU HAVE ENTERED ARE:
 1-ALERT COST
 2-POLITICAL COST
 3-MILITARY RISK
IF THESE VALUES ARE CORRECT TYPE GO: GO
```


Figure 2-3

THE COMPUTER AS A RECORDER OF THE PROBLEM STRUCTURE

Note that the computer periodically repeats what the user has typed in to verify the accuracy of the inputs. The computer will then ask for the input values associated with this problem structure (see Figure 3-1).

3.0 ASSESSING INPUTS

The analyst or the user must quantify the uncertainty about the event outcomes in terms of probabilities and must also express the desirability (or, alternatively, the lack of satisfaction) of the option and outcome combinations on the dimensions identified earlier. Because the outcomes are defined so that they are independent of the options (i.e., do not change as a function of the option), the probability assessment may take a relatively small proportion of the effort devoted to preparing inputs. The value assessments are generally much more difficult and time-consuming. Initially, however, both of these inputs can be approximations rather than the most accurate possible reflections of uncertainty and value. Approximations are acceptable because the option screening computer program, OPINT, facilitates the testing of the sensitivity of the output to changes in the input numbers.

3.1 Probabilities of the Outcomes

Among statisticians and others interested in the study and use of probabilities as a measure of uncertainty, there are presently two main schools of thought about how probabilities should be defined. One is the "objectivist" or "frequentist" school which maintains that the probabilities of outcomes can only be found from the long-run relative frequency of occurrence of outcomes of identical events. The other is the "subjectivist" or "personalist" school which says that probability is a measure of someone's degree of belief that an outcome will occur.[1] The latter definition is generally used by decision analysts since rarely is the decision problem studied one which has occurred exactly in the same form many times in the past. For instance, in the Warsaw Pact attack example, we cannot look at the past and say that identical circumstances have occurred repeatedly and that sometimes the Pact attacked and sometimes it did not. Rather than trying to get a relative frequency measure of the probability, the analyst or user of the procedure tries to quantify the degree of belief of some expert. Many experiments have been carried out in order to arrive at guidelines for ways of eliciting this probabalistic information in different circumstances.[2] The expert, or a

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[1]For further discussion, see Raiffa, op. cit., pp. 273-76 or an elementary text on Bayesian statistics.

[2]See for example, Brown, Kahr, and Peterson, op. cit., chapters on probability assessment; or C. S. Spetzler and C.-A. S. Stael von Holstein, "Probability Encoding in Decision Analysis," Management Science 22 (1975): 340-58.

group of experts, is asked questions like: "Which outcome is most likely?" and "How many times more likely is this than the next most likely?" "Than the least likely?" Eventually the replies can be consolidated into probabilities (or percentages) for the different outcomes.

In the Warsaw Pact attack example, the expert considered many intelligence reports of recent Soviet domestic affairs, Soviet activities in the Mediterranean, Warsaw Pact countries' military maneuvers, and the like. This background information is shown in Figure 5-1. Considering this information, the expert eventually arrived at probabilities of 0.10 for the outcome Warsaw Pact attack and 0.90 for the outcome no attack. (The list of outcomes whose probabilities are assessed must be exhaustive; that is, their probabilities must add to 1.00 or to 100 when expressed as a percentage.)

The assessment of the probabilities is more complicated if:

- The assessor is periodically receiving new information and would like to update the probabilities to reflect this information; or

- The uncertain event of interest is actually the last of a series of other uncertain events and its probabilities are conditioned by how the other events turn out.

Both these situations are discussed in Section 5.

3.2 Values of the Option-Outcome Combinations

The structure of the decision problem determines the value dimensions and the option-outcome combinations for whose consequences the values must be assessed. For the Warsaw Pact attack example, the user provides the numbers to fill the matrices displayed in Table 3-1. Assessing these values can be difficult because, in most simplified examples such as this, each value dimension is a composite and so may have no natural scale. When this is the case, an arbitrary scale is established. The user or expert whose judgments are to be quantified is then asked a series of questions which require considerable thought to answer. These questions are designed to elicit the user's feelings about how the option-outcome combinations rate on the selected arbitrary scale.

There are two general types of arbitrary scales, either of which can be used in a decision problem. One is an absolute scale called "payoffs," the other a relative scale

ALERT COST	Pact Attack	No Pact Attack
Maintain Status Quo		
Military Vigilance		
Simple Alert		
Reinforced Alert		

POLITICAL COST	Pact Attack	No Pact Attack
Maintain Status Quo		
Military Vigilance		
Simple Alert		
Reinforced Alert		

MILITARY RISK	Pact Attack	No Pact Attack
Maintain Status Quo		
Military Vigilance		
Simple Alert		
Reinforced Alert		

Table 3-1 — VALUE MATRICES FOR THE WARSAW PACT ATTACK EXAMPLE

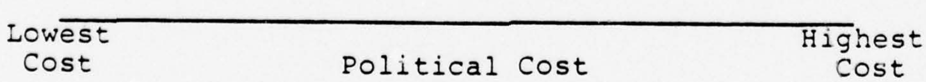
called "regret." The payoff scale is described briefly. The regret scale, which is the recommended scale for the decision problems discussed here, is described at length.

3.2.1 Payoffs - Consider the value dimension "political cost" in the Warsaw Pact attack example. There are eight possible option-outcome combinations shown in Table 3-2.

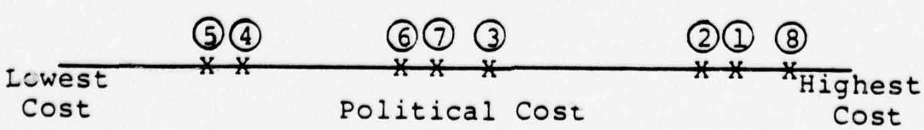
	Pact Attack	No Pact Attack
Maintain Status Quo	1	5
Military Vigilance	2	6
Simple Alert	3	7
Reinforced Alert	4	8

Table 3-2 — POSSIBLE OPTION-OUTCOME COMBINATIONS

They range from maintaining the status quo and a pact attack (combination 1) to reinforced alert and no attack (combination 8). One way to think of the value problem is by imagining an arbitrary political cost scale along which the assessor must scatter points representing option-outcome



combinations in positions that show their relative desirability. A hypothetical scattering is shown below. The circled numbers represent the option-outcome combinations (the cells) of Table 3-2.



The values read off this scale fill the "political cost" value matrix, which is analogous to the payoff table prepared in an elementary decision analysis exercise.

3.2.2 Regret - An alternative way of expressing the "political cost" value is to consider one column of the matrix at a time (corresponding to one of the outcomes of the uncertain event) and within the column to make judgments about the relative cost (value) of different possible options under that outcome as compared to the best option. For instance, if, on the assumption that there will be a pact attack, what is the best option? And then what are the values of all the other options compared to that best option? This process is analogous to preparing a "regret table" in elementary decision analysis. Many users find it easier to think about "regrets" under a specific assumption about the outcome than to make judgments about payoffs where the users must consider both different outcomes and different options at once. For this reason the regret scale is used in these examples.

In order to respond to questions like "How" -- in terms of regret--"does the value of option 1 compare to that of option 2?" the units in which regret is measured must be chosen. The decision is an arbitrary one which can be handled as shown in steps 1 and 2 below. Suppose that you are the assessor whose values are being elicited.

3.2.3 Rules for filling a regret matrix

Arbitrary Establishment of the Units

1. If you make the decision which is best for a particular event outcome, then you have no regret. Therefore, within each column, identify the option that would be optimal if the outcome of the uncertain event were that indicated by the column under consideration. Set the regret of that cell equal to zero. When you have finished, each column will contain a cell with zero in it. This cell establishes one end of the regret scale within each column.

2. Within each column, identify the worst option. Then for each column think about how you feel on the dimension of value being considered about going from the best to the worst option in that column. You have no regret with the best option, but you may have a great deal of regret with the worst option. Then, for each column, decide which of these transitions from best to worst option involves the greatest incremental increase in regret. Assign a value of -100 to the worst option cell in the column where this increase in regret is greatest.

Relative Value Assessments

3. For the column containing both a zero value and a -100 value, assign values between 0 and -100 to the rest of the cells which reflect the relative regret of each cell compared to the -100 cell. For example, if the amount of your regret in going from the zero cell to another cell is about 1/4 of that for going from the zero cell to the -100 cell, then the other cell should have a value of about -25.

4. Next, consider the minimum-to-maximum regret cells of another column in comparison to the 0 to -100 cells of the previous column. Use your feelings about this regret difference to establish the value of the maximum regret cell for the new column. For example, if you think it is about half as bad to go from the best to the worst option for this new column as going from the 0 to the -100 options in the previous column, then the maximum regret cell of the new column should have a value of -50.

Repeated Assessments

5. The procedure of step 3 is repeated to get all the cell values within each column, and that of step 4 is repeated to determine the worst regret value in each column before the intermediary cells are filled.

Adjustments

6. Once the cells have been filled, various pair-wise comparisons are made to test and increase the consistency of the assessments. In these pair-wise comparisons, the <u>difference</u> between the regret values for one pair is compared to the <u>difference</u> between values for another pair. These comparisons can be made both within a column and across columns.

3.2.4 <u>Regret assessment example: Warsaw Pact attack</u> - The regret assessment is more easily understood in the context of a particular example than by merely listing the assessment rules. Furthermore, specific problems sometimes have special features that reduce the number of judgments needed. Consider first the political cost dimension of the Warsaw Pact attack problem. The regret matrix to be filled is shown in Table 3-3A. Following the rules explained above, the assessor looks first at each column separately to find its zero-regret cell. If the event outcome is attack, the best option from a political standpoint is the maximum alert

POLITICAL COST

A.

	Attack	No Attack
Maintain Status Quo		
Military Vigilance		
Simple Alert		
Reinforced Alert		

B.

	Attack	No Attack
Maintain Status Quo		0
Military Vigilance		
Simple Alert		
Reinforced Alert	0	

C.

	Attack	No Attack
Maintain Status Quo	-100	0
Military Vigilance		
Simple Alert		
Reinforced Alert	0	-100

D.

	Attack	No Attack
Maintain Status Quo	-100	0
Military Vigilance	-35	
Simple Alert	-10	
Reinforced Alert	0	-100

E.

	Attack	No Attack
Maintain Status Quo	-100	0
Military Vigilance	-35	-20
Simple Alert	-10	-50
Reinforced Alert	0	-100

Table 3-3 – APPLICATION OF RULES FOR FILLING REGRET MATRIX

posture, namely reinforced alert; this option avoids, for example, the loss of face in being taken by surprise; consequently, this cell is given a zero value. On the assumption there will be no attack, on the other hand, the best option (zero regret) from the standpoint of political costs is simply to maintain the status quo. Table 3-3B shows the appearance of the regret matrix after these judgments are made.

Next, the worst option (maximum regret) under each outcome is noted. In this case the worst decisions are if there is an attack, maintain status quo, and if there is no attack, reinforced alert. The assessor must decide whether there is more regret, on the political cost dimension, in going from the best to worst option under the attack outcome compared to going from the best to worst option under the no attack outcome. Another way of phrasing this question is, "Is it a bigger mistake politically to have failed to go on alert if there is an attack or to have gone on alert when there is no attack?" It happens in this particular example, that because the assessor feels that those two shifts are <u>equally</u> bad, the "worst option" cell in each column is assigned a value of -100. (See Table 3-3C.)

The next step in the regret assessment is to fill in the intermediary values in the column containing both a 0 and a -100. (In this example either column satisfies that requirement.) We begin with the attack column. After some thought, the assessor comes up with the values shown in Table 3-3D. These values imply that, of the total (political cost) regret possible from being wrong on the decision (i.e., selected the wrong option) the event outcome is attack, only about a tenth of that is incurred by going on a simple alert instead of a reinforced alert and about a third is incurred in choosing the military vigilance option rather than reinforced alert. One way to explain these values is that the assessor feels that the political cost of being in a less than maximum alert posture (compared to being in the maximum alert posture) if an attack develops is quite a bit less serious than having maintained the status quo. In other words, having gone to some level of greater alert (exactly which level is not as crucial) is much better from a political viewpoint than having done nothing.

The regret values for the second column can be assessed directly since this column also contains both 0 and -100 values. (If the regret of going from best to worst decision here had been less than that of going from best to worst in column 1, then the maximum regret value for this column would have been assessed as something less than -100,

for example, -67 if the maximum amount of regret in column 2 were thought to be about 2/3 that of column 1. The rest of the values in column 2 are estimated following the same procedure as described for column 1. The results of this assessment appear in Table 3-3E.

All the assessments in the matrix can then be checked (and adjusted if necessary) by making pair-wise assessments of the values. For example, the assessor's feelings of regret should be twice as serious going from the 0 to -20 cells in column 2 as going from the 0 to -10 cells in column 1.

Taken together, these feelings imply that, in the opinion of the assessor, having gone to military vigilance when in fact there is no attack is twice as serious a mistake as having gone only to simple alert when an attack does occur.

The regret matrices for the other two dimensions, military risk and alert cost, are assessed in the same manner as the political cost. In assessing military risk, for example, the zero regret cells are identified as shown in Table 3-4. Furthermore, the assessor concludes here that, militarily speaking, there is no regret in being over-prepared for an attack which does not materialize. For this reason all the cells in column 2 are zero. The worst option on the assumption that there is an attack is to maintain the status quo; accordingly, that cell receives a regret value of -100 (see Table 3-4B). The rest of the values were assessed as shown in Table 3-4C.

The final value dimension, alert cost, is meant to be a measure of the out-of-pocket costs of going from the status quo to the various levels of alert. However, rather than trying to figure out these costs in dollars, they will also be approximated by regret on a scale of 0 to -100. If the objective is to minimize regret on a cost dimension, then the best option (that having the lowest cost) is to maintain the status quo and the worst is to go to the reinforced alert. These regrets are, therefore, 0 and -100, respectively. Since the cost and, consequently, the regret remains the same, whether there is an attack or not, both columns of the regret matrix for alert cost will be the

A.

	Attack	No Attack
Maintain Status Quo		0
Military Vigilance		
Simple Alert		
Reinforced Alert	0	

B.

Maintain Status Quo	-100	0
Military Vigilance		0
Simple Alert		0
Reinforced Alert	0	0

C.

Maintain Status Quo	-100	0
Military Vigilance	-45	0
Simple Alert	-15	0
Reinforced Alert	0	0

Table 3-4 — MILITARY RISK

same. The values obtained during this assessment for the different cells of the matrix are shown in Table 3-5.

	Attack	No Attack
Maintain Status Quo	0	0
Military Vigilance	-30	-30
Simple Alert	-70	-70
Reinforced Alert	-100	-100

Table 3-5 — ALERT COST

In applying the general rules for filling a regret matrix to this example, several special features of the example became apparent. These were:

- In the political cost matrix, the amount of regret incurred in going from the best to worst option under one outcome (attack) was felt to be the same as the amount incurred in going from the best to worst option under the other outcome (no attack). (Both columns contained a 0 and a -100.)

- For the military cost matrix under the outcome of no attack, none of the non-optimal options resulted in any regret when compared to the optimal one. (All the entries of the second column were 0.)

- In the alert cost matrix, the amount of regret was the same regardless of which outcome was assumed to occur. (Column 1 is identical to column 2.)

One feature of measures of regret which should be kept in mind when regret matrices are used is that making comparisons of values across columns is somewhat tricky. Regret values within a column are all measures of the value of a cell <u>relative</u> to that of the optimal cell for that column. The basis for these relative values must be kept in mind for a comparison of regret values across columns. If two cells in different columns both contain the regret value of -35, for instance, then the assessor feels as bad about going from the optimal cell in one column to its -35 cell as about going from the optimal cell in the other column to its -35 cell. This equivalence is in contrast to the interpretation of the entries in a payoff matrix. For a payoff matrix the values in the cells are measured in absolute terms. If two cells in different columns have the same payoff, then the assessor feels equally good (or bad) about <u>being</u> in either of the states. For two regret cells having equal values, the assessor feels equally good about the <u>transition</u> to that cell from the optimal cell in its column. Statements involving the comparison of incremental regrets can also be made. For example, if the difference between two regrets in one column is, say, 20, this <u>is</u> the same amount of regret as that between any two regrets in another column which also differ by 20.

3.3 Weights for the Value Dimensions

After the assessor's feelings about regret have been elicited for each of the different value dimensions, these figures are combined into a single value for every decision option-event outcome combination. This composite regret matrix, called the "combined valuation," is formed by taking

a weighted average of the matrices over the different value dimensions. The average is weighted because in most examples certain of the dimensions are more important than others. These weights are assessed as part of this analysis.

When values over different dimensions are expressed in terms of regret, their weights are called the "swing weights" and are estimated not by considering the overall difference in importance of one dimension compared to another, but rather by estimating the importance of a swing from the best (regret = 0) to worst (regret = -100) option in one column of one dimension compared to the swing from the best to worst option on another dimension. For example, consider the regret matrices in the Warsaw Pact attack case shown in Table 3-6. Now suppose the assessor first considers the military risk compared to political cost and decides that the military risk regret of going from zero (reinforced alert if an attack occurs) to -100 (maintaining status quo if an attack occurs) is twice as important as the political cost regret of going from zero to -100 under the same conditions; that is, the swing weight for military risk is twice the swing weight for political cost. Suppose further that the assessor decides that the alert cost regret from having spent the money to go from zero (maintaining status quo) to -100 (going on reinforced alert) is about equal in importance to the political cost regret of going from zero (reinforced alert if there is an attack) to -35 (military vigilance, if there is an attack). This implies that the political cost swing weight is about three times that of the alert cost. To summarize these assessments:

military risk importance = 2 x political cost importance

political cost importance = 3 x alert cost importance.

Maintaining these relationships and normalizing the weights so that they add to 1.00 give:

Value Dimension	Importance Weight
Military risk	0.6
Political cost	0.3
Alert cost	0.1

3.4 Providing Inputs to the Computer Program

Once the probabilities, the values on the various dimensions, and the weights of the different dimensions have been assessed, they are fed into the computer in response to questions generated by the computer. These questions are based on the problem structure previously communicated to

	Political Cost		Military Risk		Alert Cost	
	Attack	No Attack	Attack	No Attack	Attack	No Attack
Maintain Status Quo	-100	0	-100	0	0	0
Military Vigilance	-35	-20	-45	0	-30	-30
Simple Alert	-10	-50	-15	0	-70	-70
Reinforced Alert	0	-100	0	0	-100	-100

Table 3-6 — REGRET MATRICES FOR ALL THREE VALUE DIMENSIONS

the computer. This procedure is illustrated in Figure 3-1 for the Warsaw Pact Attack example.

The computer program has several features that facilitate the input of this data. Two examples are: the labels given when the problem structure is specified are repeated by the program so that the user can verify their accuracy and make changes if necessary, and the values of the weights and of the probabilities are normalized (i.e., made to add to 1.00 or 100%) in case the values given by the user do not fulfill this requirement.

```
ENTER THE FOLLOWING VALUATIONS
                        ALERT COST
           ATTCK  NOATK
MAINTAIN    0      0--
MIL.VIG.   -30    -30
SIMPLE     -70    -70-                          REGRET
REINFRCD   -100   -100                          VALUES
                       ALERT COST


           ATTCK  NOATK
MAINTAIN     0      0
MIL.VIG.   ¯30    ¯30
SIMPLE     ¯70    ¯70
REINFRCD   ¯100   ¯100
IF THESE VALUES ARE CORRECT TYPE GO  GO


                        POLITICAL COST
           ATTCK  NOATK
MAINTAIN   -100    0--
MIL.VIG.   -35    -20--
SIMPLE     -10    -50-
REINFRCD   0      -100-


                        POLITICAL COST
           ATTCK  NOATK
MAINTAIN   ¯100     0
MIL.VIG.    ¯35   ¯20
SIMPLE      ¯10   ¯50
REINFRCD     0    ¯100
IF THESE VALUES ARE CORRECT TYPE GO  GO

                        MILITARY RISK
           ATTCK  NOATK
MAINTAIN   -100   0----
MIL.VIG.   -45    0----
SIMPLE     -15    0----
REINFRCD   0      0----


                        MILITARY RISK
           ATTCK  NOATK
MAINTAIN   ¯100     0
MIL.VIG.    ¯45     0
SIMPLE      ¯15     0
REINFRCD     0      0
IF THESE VALUES ARE CORRECT TYPE GO  GO

NOW ENTER THE WEIGHTS ASSOCIATED WITH EACH VALUATION
ALERT COST              10----
POLITICAL COST          30----                  WEIGHTS
MILITARY RISK           60----

THE NORMALIZED WEIGHTS YOU HAVE ENTERED ARE
ALERT COST                 10
POLITICAL COST             30
MILITARY RISK              60
IF THESE VALUES ARE CORRECT TYPE GO  GO


ARE INITIAL PROBABILITIES CONDITIONAL ON SOME EVENT? NO
     ENTER THE PROBABILITIES OF EACH STATE

                 ATTCK  NOATK
PROBABILITY       10     90---
NORM. PROB.          10     90


IF THESE VALUES ARE CORRECT TYPE GO  GO
```

(Characters typed by the user are underlined.)

Figure 3-1

EXAMPLE OF A WAY TO PROVIDE INPUTS TO THE COMPUTER PROGRAM
(WARSAW PACT ATTACK EXERCISE)

4.0 CALCULATIONS

Once the decision problem has been structured, the inputs assessed, and this information fed into the computer, some straightforward calculations are made to enable the user to determine the best decision option.

4.1 Combined Valuation

By means of the importance weights discussed above, the different regret matrices are combined into a single matrix expressing the combined effects of regret on different dimensions. The result of this computation is shown in Table 4-1 on the following page. The assumptions are made that the different dimensions of value are independent and that they combine according to an additive rule. Under these assumptions, each cell in the combined valuation matrix is filled by taking the weighted average of the regret values in the corresponding cells of the three value dimension matrices. For example, the following computation produces the value of -19 in the simple alert-attack cell:

$$(-10 \times 0.30) + (-15 \times 0.60) + (-70 \times 0.10) = -19.$$

As is the case with the individual regret matrices, the values of cells in this combined matrix incorporate an understood comparison with the value of the optimal cell in each column. In the combined value matrix, however, the optimal cell for each column will not necessarily have a zero value, since the combined valuation is a weighted sum of the individual value matrices. For instance, in the Warsaw Pact attack example, the "Attack" column of the combined valuation matrix no longer has a zero entry. Before comparisons can be made of the absolute values of the regret from column to column, the zero must be restored, in this case by adding 10 to every entry in that column. (Whether this adjustment is made or not has no effect upon the choice of the optimal act since the addition of the same constant to each row of the matrix will not change which row has the smallest expected regret, the choice criterion discussed in the next section.) Without making this adjustment, however, the differences between entries within one column can be compared to entry differences in another column. For example, the amount of regret (9 units) in going from zero to -9 in the second column is the same as that of going from -10 to -19 in the first column. However, before the adjustment, the amount of regret from being in the military vigilance-attack cell (regret = -40) is not the same (-40) as that of being in the reinforced alert-no attack cell.

	Political Cost			Military Risk			Alert Cost			Combined Valuation	
Importance Weights	0.30			0.60			0.10				
	X			X			X				
	Attack	No Attack		Attack	No Attack		Attack	No Attack		Attack	No Attack
Maintain Status Quo	-100	0		-100	0		0	0		-90	0
Military Vigilance	-35	-20	+	-45	0	+	-30	-30	=	-40	-9
Simple Alert	-10	-50		-15	0		-70	-70		-19	-22
Reinforced Alert	0	-100		0	0		-100	-100		-10	-40

Table 4-1 — REGRET MATRICES FOR ALL THREE VALUE DIMENSIONS COMBINED INTO A SINGLE MATRIX

4.2 Expected Value

The criterion used here for indicating the best decision option is that having the smallest expected regret, measured from the values of the combined valuation matrix. Expected regret is computed for each option by multiplying the value of each outcome under that option by the outcome's probability. For example, the option "reinforced alert" has combined regret values of -10 if there is an attack and -40 if there is no attack. Weighting these values by the probabilities for the two outcomes gives:

$$(-10 \times 0.10) + (-40 \times 0.90) = -37.$$

Carrying out the computation for the other three options gives the expected regret values shown in Table 4-2. Since the smallest expected regret value is 9 (ignore the minus signs, which are included merely to remind the assessor that regret is a measure of undesirability), the associated option, maintaining the status quo, is, therefore, the optimal decision on the basis of the data input.

4.3 Sensitivity

The expected regret values for each of the four options considered here depend on the three kinds of inputs to the analysis: the regret matrices for the different dimensions, the importance weights for the different dimensions, and the probabilities. One way to obtain these input values is to spend a lot of time and effort in making the assessments. Generally, however, a more efficient way to conduct the analysis is to assess quickly some approximate numbers for use in an initial pass through the whole procedure. The final step in the option screening method then becomes a sensitivity analysis where changes are made to the inputs to see their effect upon the solution, that is, the choice of the option having the smallest expected regret.

4.3.1 Probabilities - The expected regret for each option is a linear function of the corresponding row in the combined valuation matrix with the probabilities serving as coefficients. Changes in the probabilities of attack versus no attack will cause changes in the values of the expected regret and may cause a change in the optimal option, that is, which option has the smallest expected regret. Because of the linearity of the relationship, the effect of probability changes on expected regret can be easily shown graphically. In Figure 4-1, four lines are plotted. Each of these, one for each option, is an expected regret line. The points composing the line show the change in expected regret (the vertical scale) for changed values of the probability of attack (the horizontal scale). (The probability of no

COMBINED VALUATION

	Attack	No Attack
Maintain Status Quo	-90	0
Military Vigilance	-40	-9
Simple Alert	-19	-22
Reinforced Alert	-10	-40

X

PROBABILITY OF THE OUTCOMES

Attack	No Attack
0.10	0.90

=

EXPECTED VALUE OF THE REGRET*

-9
-12
-22
-37

*Computer rounds off figures to nearest integer

Table 4-2 — COMPUTATION OF THE EXPECTED VALUE OF THE COMBINED REGRET

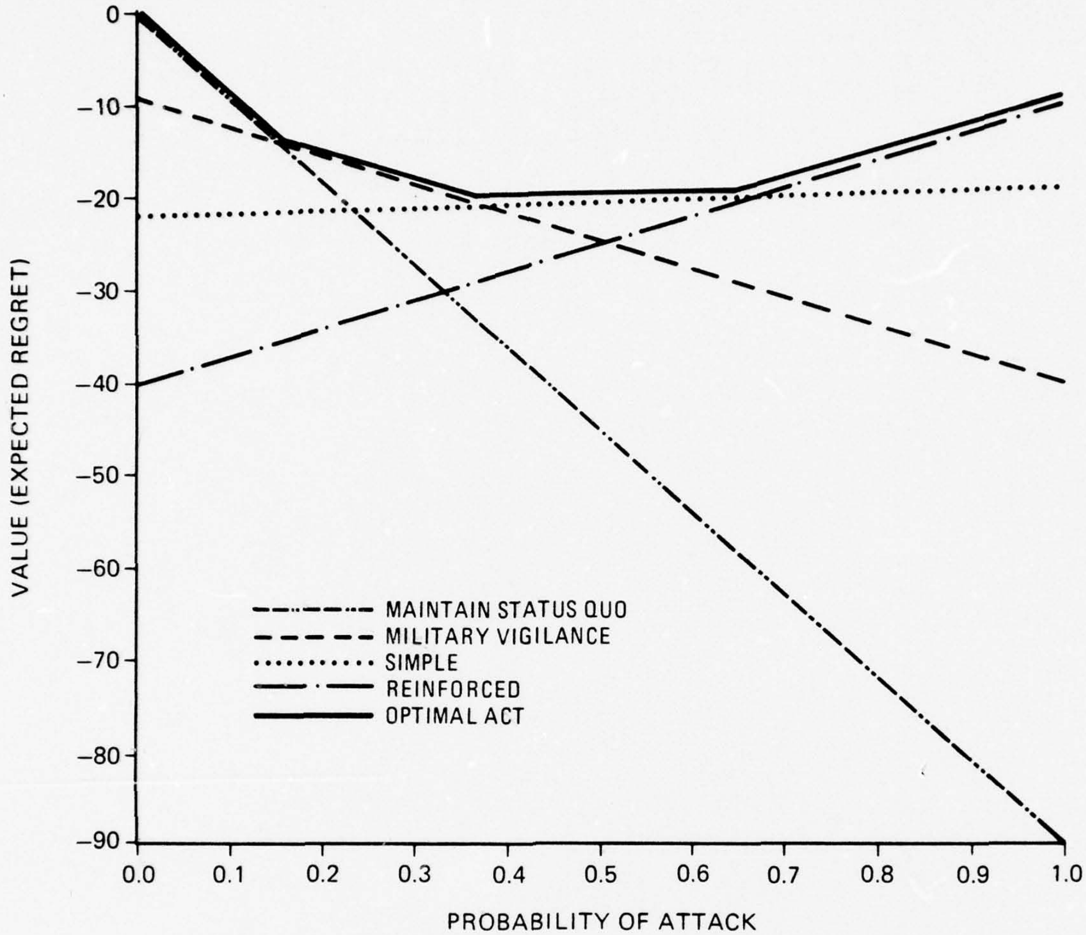


Figure 4-1

CHANGES IN EXPECTED REGRET AS A FUNCTION OF PROBABILITY OF ATTACK: GRAPHIC PRESENTATION

attack is simply one minus the probability of attack.) The expected regret scale runs from largest to smallest so that the smallest (most desirable) values will be at the top of the graph. In response to the request "SENSITIVITY," the computer provides a matrix of values of the expected regret for each option corresponding to a number of probabilities of attack in the range from 0.0 to 1.0. Using any two of these regret values for each option to determine the option line, the assessor can sketch in all four expected regret lines. An inspection of this graph enables the assessor to see at a glance the effect of changes in the probability assessment upon the choice of the optimal option. The

option whose expected regret line is uppermost is the optimal act. In this example from the Warsaw Pact exercise, the status quo option is optimal until the probability of attack reaches about 0.17; at that point, military vigilance becomes optimal and remains so until the attack probability exceeds about 0.38, when simple alert becomes the option whose expected regret is smallest. The option of reinforced alert does not become optimal until the attack probability reaches 0.67. These points at which there is a shift in the optimal act are referred to as the "thresholds" of the probabilities.

If the assessor is interested in the sensitivity of the solution to only a few specific changes in the probability, then he can simply request the computer program option "CHANGE PROB," rather than draw out the graph. The program will then display the current probability values and ask the assessor for the new probabilities. All the computations will be repeated using the new numbers and the expected regret tabulated under the original and revised probability assessments. Figure 4-2A shows the way in which four new probability assessments are fed into the computer.

4.3.2 Values and importance weights - Holding the probability of attack constant (at the initial value of 0.10, for example), the user can also test the sensitivity of the output to changes in the importance weights, which will change the combined value matrix, and even to individual changes within any of the regret matrices for the different value dimensions. The simple procedure by which such changes are incorporated into analysis by using the computer aid is illustrated in Figure 4-2B and C, which have as their example changes in the importance weights. First, the values of the weights are changed (Figure 4-2B); next, the effect of these changes upon the combined value matrix and the expected regret is displayed at the user's request (Figure 4-2C).

A. Changing the Probabilities

```
                ATTCK NOATK
CURRENT
PROBABILITY       10    90                Original Probabilities
NEW PROBS.       ___   ___

NEW PROBS.       25    75_                First New Assessments
NORMALIZED PROBABILITIES -    25   75
IF THESE VALUES ARE CORRECT TYPE GO: GO

NEW PROBS.       40    60_                Second New Assessments
NORMALIZED PROBABILITIES -    40   60
IF THESE VALUES ARE CORRECT TYPE GO: GO

NEW PROBS.   50      50___                Third New Assessments
NORMALIZ"D PROBABILITIES -    50   50
IF THESE VALUES ARE CORRECT TYPE GO: GO

NEW PROBS.   80      20___                Fourth New Assessments
NORMALIZED PROBABILITIES -    80   20
IF THESE VALUES ARE CORRECT TYPE GO: GO
```

Expected Regret Under Each Option For the Original (Estimate #0) and the New Probability Assessments.

A REVIEW OF YOUR PROBABILITY ESTIMATES

	ESTIMATE #				
	0	1	2	3	4
MAINTAIN	¯9	¯22	¯36	¯45	¯72
MIL.VIG.	¯12	¯17	¯22	¯25	¯34
SIMPLE	¯22	¯21	¯21	¯20	¯20
REINFRCD	¯37	¯32	¯28	¯25	¯16

(Characters typed by the user are underlined.)

Figure 4-2

USING THE COMPUTER PROGRAM TO MAKE SENSITIVITY CALCULATIONS

B. Changing the Importance Weights

Request the Editing Option:

```
SELECT ANY SINGLE OPTION BY TYPING A CHARACTER UNDER ITS POINTER

 ┌──DISPLAY RESULTS
 |     ┌──CHANGE VARIABLES
 |     |     ┌──CHANGE PROB.
 |     |     |     ┌──CHECK INDICATORS
 |     |     |     |     ┌──LOAD MODEL
 |     |     |     |     |     ┌──CREATE NEW MODEL
 |     |     |     |     |     |     ┌──SAVE MODEL
 |     |     |     |     |     |     |     ┌──PLOTTING PTS.
_|_   _|_   _|_   _|_   _|_   _|_   _|_   _|_

     x
```

Select the Input Variable to be Changed:

```
SELECT ANY SINGLE OPTION BY TYPING A CHARACTER UNDER ITS POINTER

           THE FOLLOWING VALUES MAY BE EDITED
 ┌──STATE PROBABILITY
 |     ┌──COMBINED VALUE
 |     |     ┌──VALUE WEIGHTS
 |     |     |     ┌──VALUES
 |     |     |     |     ┌──COND. LIKELIHOOD
 |     |     |     |     |     ┌──INDICATORS
 |     |     |     |     |     |     ┌──ADD ACTION
_|_   _|_   _|_   _|_   _|_   _|_   _|_
             x
```

Change Weights:

```
              VALUE WEIGHTS
  VALUATION                  WEIGHT
  ALERT COST                   10
  POLITICAL COST               30
  MILITARY RISK                60

  WEIGHTS         10  45     45
  NORMALIZED WEIGHTS     10    45    45
  IF THESE VALUES ARE CORRECT TYPE GO: GO
```

Figure 4-2 (continued)

C. Results of the Change in Weights

```
SELECT ANY SINGLE OPTION BY TYPING A CHARACTER UNDER ITS POINTER

          THE FOLLOWING DISPLAYS ARE AVAILABLE
 ┌¯¯EXPECTED VALUE
 |    ┌¯¯COMBINED VALUE
 |    |    ┌¯¯STATE PROB.
 |    |    |    ┌¯¯VALUES
 |    |    |    |    ┌¯¯VALUE WEIGHTS
 |    |    |    |    |    ┌¯¯COND. PROBABIL.
 |    |    |    |    |    |    ┌¯¯COND. LIKELIHOOD
_|_  _|_  _|_  _|_  _|_  _|_  _|_

      x

 x
```

First, Combined Value is Selected, Then Expected Value is Selected

```
                                 COMBINED VALUE
             ATTCK  NOATK
MAINTAIN      ¯90      0
MIL.VIG.      ¯39    ¯12
SIMPLE        ¯18    ¯29
REINFRCD      ¯10    ¯55

PRESS EXECUTE TO CONTINUE
```

```
                                 EXPECTED VALUE *
             ATTCK  NOATK   TOTAL
MAINTAIN       ¯9      0      ¯9
MIL.VIG.       ¯4    ¯11     ¯15
SIMPLE         ¯2    ¯27     ¯28
REINFRCD       ¯1    ¯49     ¯50
```

*In this example, the optimal decision remains "maintain status quo" with a value of 9. The worst decision, "reinforced alert," now has an expected value of 50 compared to its value with the original importance weights of 37.

Figure 4-2 (continued)

5.0 SPECIAL TOPICS IN PROBABILITY ASSESSMENT

5.1 Updating the Probability Assessment

Besides moving the probabilities for different outcomes of the uncertain event through a range of values during the sensitivity analysis, the user may also want to recalculate the expected regret for each decision option based on some specific new probability values. For example, the new probabilities of interest might be revisions of the probabilities for the uncertain event resulting from the acquisition of some new data. In the Warsaw Pact Attack exercise, the initial assessments of the probabilities of attack or no attack were made by a military expert who was provided with background information about recent Soviet armed forces and political activity at home, in the Mediterranean, and elsewhere (see Table 5-1).

JULY - DECEMBER 1974

THE USSR CONTINUES TO EXPAND HER INFLUENCE AROUND THE WORLD. HER OVERALL OBJECTIVE APPEARS TO BE THE WEAKENING OF NATO THROUGH A SERIES OF DEMARCHES FROM PEACEFUL COEXISTENCE WITH WESTERN EUROPE TO EXERTING PRESSURE IN THE FORM OF DEEPER POLITICAL PENFTRATION IN THE AREAS OF THE NORTHERN AND SOUTHERN REGIONS OF THRACE, THE PERSIAN GULF AND THE INDIAN OCEAN.

THE USSR HAS BEEN PUTTING CONSISTENT PRESSURE ON TURKEY TO ALLOW FREE PASSAGE OF ALL SOVIET SHIPS THROUGH THE TURKISH STRAITS, RECENTLY THE USSR HAS PRESSURED GREECE TO ALLOW BULGARIA AN OUTLET TO THE AEGEAN SEA BY GRANTING FREE PASSAGE THROUGH GREGIAN THRACE.

DURING NOVEMBER AND DECEMBER OF 1974 AND THROUGH JANUARY OF 1975, THE SOVIETS INCREASE THEIR NAVAL ACTIVITY IN EVERY OCEAN. INTERFLEET TRANSFERS HAVE CONCENTRATED FORCES IN THE MEDITERRANEAN, OFF THE SHETLANDS, AND IN OTHER STRATEGIC MARITIME AREAS.

AS A RESULT OF INCREASED NUMBER OF SOVIET VESSELS AT SEA AND THE SOVIET NAVAL DEPLOYMENTS, IT APPEARS A MARITIME EXERCISE MIGHT BE CONDUCTED IN BOTH THE MEDITERRANEAN AND THE NORTH SEA. PRAVDA HAS RECENTLY REFERRED AT LEAST TWICE TO UPCOMING NAVAL MANEUVERS.

JANUARY 1-15, 1975

- O INCREASED SOVIET INTERFLEET TRANSFERS WITH WHAT APPEARS TO BE A MODERATE BUILD-UP OF ATLANTIC AND MEDITERRANEAN FLEETS.
- O A NUMBER OF PERSONNEL CHANGES IN KEY POSITIONS OCCUR IN THE USSR BUT NOT AT THE TOP.
- O OFFICIAL SPEECHES AND PRAVDA ARTICLES BECOME MORE HOSTILE TOWARD WEST. DEMANDS FOR MORE FAVORABLE ECONOMIC TRADE ARRANGEMENTS ARE MADE.
- O USSR LAUNCHES TWO NEW SURVEILLANCE SATELLITES.

Table 5-1 — BACKGROUND FOR WARSAW PACT ATTACK EXAMPLE

JANUARY 16-22

- O AFTER AN UNUSUAL MEETING OF THE SOVIET POLITBURO, MOSCOW ANNOUNCES THAT THE POLITBURO APPROVED A NEW THREE-YEAR PLANNED ECONOMIC GROWTH PROGRAM, WHICH REQUIRES CURTAILMENT OF THE PRODUCTION OF MANY LUXURY AND CONSUMER ITEMS.
- O A MOSCOW CONFERENCE OF SEVERAL MILITARY LEADERS OF WARSAW PACT NATIONS SURPRISES WESTERN INTELLIGENCE SOURCES, ALTHOUGH PACT MEMBERS CLAIM IT HAD BEEN PLANNED FOR A LONG TIME.
- O A PRAVDA ARTICLE PRAISES THE COOPERATION AND PROGRESS OF THE U.S.-USSR JOINT SPACE VENTURE.

JANUARY 23-31

- O WARSAW PACT MEETING IS COMPLETED WITH A JOINT PRESS RELEASE STATING THAT A LARGE-SCALE MILITARY FIELD EXERCISE WOULD BE HELD IN THE FORWARD AREAS THIS YEAR DURING THE SECOND AND THIRD WEEK OF MARCH 1975.
- O CLANDESTINE SUBVERSIVE INCIDENTS REPORTED IN THRACE AREA APPEAR TO BE INCREASING. SACEUR REQUESTS INCREASED FREQUENCY IN REPORTING.
- O MOSCOW REASSIGNS TWO AND POSSIBLY THREE DIVISIONS TO THE CENTRAL FRONT FROM THE INTERIOR AND STATES IT WAS BEING DONE AT THIS TIME IN ORDER FOR THEM TO BE ABLE TO PARTICIPATE IN THE FORTHCOMING EXERCISE.
- O A RELATIVELY LARGE NUMBER OF MILITARY AIR TRANSPORT FLIGHTS HAVE BEEN NOTED FROM THE USSR INTO POLAND AND CZECHOSLOVAKIA.

FEBRUARY 1

- O MOSCOW CHARGES U.S. AND HER ALLIES ARE ATTEMPTING TO PUT AN ECONOMIC SQUEEZE ON RUSSIA AND ARE PUTTING PRESSURE ON BOTH FRIENDLY AND NEUTRAL NATIONS TO SIDE MORE WITH THE WEST. MOSCOW WARNS THAT IT WILL NOT SIT IDLY BY AND BE PRESSURED INTO ANY UNFAVORABLE POSITIONS. MOSCOW FURTHER WARNS NORTHERN NATO COUNTRIES OF THEIR VULNERABLE POSITIONS AND THREATENS SOME VEILED FORM OF RETALIATION IF THEY CONTINUE TO SIDE SO OPENLY AND COMPLETELY WITH NATO.
- O MOSCOW LAUNCHES ANOTHER "OUT-OF-SCHEDULE" SURVEILLANCE SATELLITE.

Table 5-1 (continued)

On the basis of this information, the expert assessed a value of 0.10 for the probability that an attack by Warsaw Pact countries against NATO was in the offing and a value of 0.90 for the probability that no attack was intended (see Table 5-2). The expert subsequently revised these figures

DATA		PROBABILITY ASSESSMENT	
		PACT ATTACK	NO PACT ATTACK
INITIAL	THROUGH 1 FEB	10	90

Table 5-2 – INITIAL PROBABILITY ASSESSMENTS FOR THE WARSAW PACT ATTACK EXAMPLE

six times to show the change in his degree of belief that an attack was intended, as new data became available. The data received, the revised probabilities, and the effect of these revisions upon the expected value for each decision option are all shown in Appendix B. In this section, we shall look in a little more detail at the first of the revisions.

5.1.1 Two ways of updating probabilities - One way to incorporate new data into a probability assessment is simply to ask the assessor directly to revise the probability values, by saying something like this: "Your original assessment was to set the probability of attack at 0.10. In light of the additional information just received, what is your estimate now of the probability of attack?" This is basically the procedure that was followed in making the revisions presented in Appendix B.

Research studies of people's behavior when asked to revise probabilities have shown,[1] however, that there is a general tendency to give an inappropriate amount of attention to the latest data when making the revised assessment. Often either too little or too much weight is given to it. The correct amount of influence to be exerted by the data can be computed mathematically by means of a standard statistical procedure known as the application of Bayes' Theorem. Bayes' Theorem is a formula by which the probability of occurrence of some outcome, given the new data, is computed. The formula makes use both of probability estimates made before the new data was available and of estimates of how likely one would be to observe the new data if, in fact, each of the possible event outcomes were to occur. The application of the theorem is shown here for the Warsaw Pact Attack example, updating the probability of attack. In this case, Bayes' theorem is written:

$$P(A|d_1) = \frac{P(d_1|A)\ P(A)}{P(d_1|A)\ P(A) + P(d_1|NA)\ P(NA)},$$

where: A = attack

NA = no attack

d_1 = first datum (see Table 5-3)

$P(A|d_1)$ = probability that A is true, given the first datum. This is the probability we seek, sometimes called the posterior probability, which means the probability in the light of some new datum.

$P(d_1|A)$ = probability of observing d_1 if in fact A is true.

---

[1]Brown, et al., op. cit., p. 478.

$P(d_1|NA)$ = probability of observing d_1 if in fact NA is true (i.e., A is not true).

$P(A)$ = initial probability that A is true. Sometimes called the prior probability because it is the probability value before the new information is received.

$P(NA)$ = initial probability NA is true.

The two initial probabilities have already been assessed, $P(A) = 0.10$ and $P(NA) = 0.90$. In order to use the formula in its present form, the decision maker must assess $P(d_1|A)$ and $P(d_1|NA)$. In words, the value $P(d_1|A)$ is the probability that the datum described in Table 5-3 would be observed if an attack were pending, whereas $P(d_1|NA)$ is the probability of observing this datum if no attack were pending. Estimating these conditional probabilities may be difficult. However, for an uncertain event having two outcomes, as is the case in the Warsaw Pact attack example, Bayes' Theorem can be conveniently restated[2] as a ratio:

$$\frac{P(A|d_1)}{P(NA|d_1)} = \frac{P(d_1|A)}{P(d_1|NA)} \; \frac{P(A)}{P(NA)}.$$

It is often easier to compute $P(A|d_1)$ with the formula expressed in this fashion. The procedure is as follows. The second half of the expression to the right of the equals sign can be computed immediately because the values of $P(A)$ and $P(NA)$ are known. To find the probabilities we seek, $P(A|d_1)$ and $P(NA|d_1)$, it is sufficient to estimate the ratio $P(d_1|A)/P(d_1|NA)$, the first expression to the right of the equals sign, since (1) from that and the earlier computed value of $P(A)/P(NA)$ we can calculate $P(A|d_1)/P(NA|d_1)$ and (2) we know that the values of $P(A|d_1) + P(NA|d_1)$ must add to 1.00 (either there will be an attack or there will not be an attack). Only one set of probability values will both

---

[2]Derived as follows:

Since $P(NA|d_1) = \dfrac{P(d_1|NA)\ P(NA)}{P(d_1|NA)\ P(NA) + P(d_1|A)\ P(A)}$, if we divide $P(A|d_1)$ by $P(NA|d_1)$, the two denominators of these expressions cancel each other and leave $P(A|d_1)/P(NA|d_1)$ as shown above.

satisfy the ratio relationship computed and add to 1.00. Therefore, the only quantity to assess, when Bayes' theorem is presented in this way, is $P(d_1 A)/P(d_1 NA)$. This quantity is called the "likelihood ratio."

5.1.2 Likelihood ratio - The likelihood ratio is, in other words, the probability that the observed data would have occurred given that the uncertain event has one outcome divided by the probability of the data's having been observed if the uncertain event has the other outcome(s). In the simple case of the Warsaw Pact attack, in which there are only two possible outcomes, the likelihood ratio becomes the probability of the data given that the intention is to attack divided by the probability of the data given that the intention is not to attack. Since all that is needed is the ratio of these two quantities, another way of asking for the information is by saying, "How many times more likely is it that this data will be observed if there is an attack pending than if there is not?" Many people find a question framed in this manner easier to answer than one which requires the numerator and the denominator to be estimated separately.

Suppose, for this example, that the expert decides that the new information shown as datum 1 in Table 5-3 is more likely to be observed if the intention is to

FEBRUARY 2

- O GERMANY, ITALY, FRANCE, AND BELGIUM ALL REPORT AN INCREASE IN THE NUMBER OF INCIDENTS NEAR MILITARY FACILITIES THAT COULD BE RELATED TO FOREIGN-INSPIRED SUBVERSIVE ACTIVITIES, PARTICULARLY DURING THE PAST 48 HOURS.

FEBRUARY 3

- O SOVIETS WARNED U.S. THAT SIXTH FLEET IS OPERATING DANGEROUSLY IN THE MEDITERRANEAN AND INTERFERING WITH SOVIET FLEET OPERATIONS.
- O WARSAW PACT MEDICAL PERSONNEL ARE ORDERED TO THEIR ACTIVE DUTY UNITS TO PARTICIPATE IN LARGE-SCALE EXERCISE. LITTLE MEDICAL PLAY HAS BEEN NOTED IN PREVIOUS EXERCISES.
- O AN ECONOMIC MISSION REPRESENTING TWO NATO COUNTRIES IS WELCOMED IN MOSCOW.

FEBRUARY 4

- O GERMAN SECURITY PERSONNEL REPORT PICKING UP A SOVIET UNDERCOVER AGENT NEWLY ASSIGNED TO GERMANY AND APPARENTLY WITH THE MISSION OF INTERFERING WITH NATO COMMUNICATIONS FACILITIES.

Table 5-3 – DATUM 1 – NEW INFORMATION RELEVANT TO THE ASSESSMENT OF THE PROBABILITIES IN THE WARSAW PACT ATTACK EXAMPLE

attack than otherwise. This means the likelihood ratio is greater than 1/1 (or, stated in terms of odds, "1 to 1"). If the assessor believes the datum is <u>twice</u> as likely if the intention is to attack than if the intention is not to attack, the likelihood ratio would be 2/1. Suppose, in this case, the expert decides the datum is more likely under the attack condition but not quite twice as likely. He might eventually come up with a ratio of something like 1.6/1 as the appropriate likelihood. Plugging this estimate into the Bayes' Theorem equation gives

$$\frac{P(A|d_1)}{P(NA|d_1)} = \frac{1.6}{1} \times \frac{P(A)}{P(NA)}$$

$$= \frac{1.6}{1.0} \times \frac{0.1}{0.9}$$

$$= 0.18;$$

therefore,

$$P(A|d_1) = 0.18 \times P(NA|d_1)$$

or

$$P(NA|d_1) = P(A|d_1)/0.18 = 5.56 \times P(A|d_1);$$

and since

$$P(A|d_1) + P(NA|d_1) = 1.00,$$

we can solve for $P(A|d_1)$ by substitution:

$$P(A|d_1) + 5.56 \times P(A|d_1) = 1.00$$

$$6.56 \times P(A|d_1) = 1.00$$

$$P(A|d_1) = 0.15.$$

Accordingly, the revised probability of attack given the new data is 0.15. The revised probability of no attack is 1.00 - 0.15 = 0.85. That the probability of attack has increased is reasonable since the expert believes the new datum is more likely to be an indicator of a pending attack than the contrary.

Suppose the assessor had considered the datum to be a much stronger indicator of a pending attack, perhaps four times as likely to occur as part of the preparation for an attack than under normal conditions. Then the likelihood ratio would be 4/1 and, according to Bayes' theorem for updating the probabilities, would give a revised probability of attack equal to 0.31 and a revised probability of no attack equal to 0.69.

The OPINT computer program automatically carries out the proper probability revision calculation under the "Bayesian update" option. The use of this option is demonstrated in Figure 5-1 for both the 1.6/1 ratio and 4/1 ratio. Notice that the program immediately types out the revised probability values and that, after probabilities are updated, a table showing the expected value of the regret for each decision option under both the initial probability and the revised probability is printed out.

5.1.3 Successive revisions - The OPINT program will also carry out successive updating of probabilities when new data are received periodically, as in the example presented in Appendix B. The likelihood ratios for the successive data are estimated and typed into the computer in the order that the data are received. The updating is performed by successive applications of Bayes' Theorem, with the initial or prior probability to which each new likelihood ratio is applied being the most recent, updated value of the probability. For example, the first revision applies the datum 1 likelihood ratio to the initial probabilities. The second revision applies the datum 2 likelihood ratio to the probabilities which are the output of the first revision, and so on.

5.2 Conditioned Probability Assessments

The preceding section showed how to update, in the course of an analysis, the probability assigned to an important, uncertain event as new information is revealed or acquired. For some decision problems, however, the assessor may feel that not even the initial probabilities of the main uncertain event can be reasonably assessed without considering some other uncertain events. When the outcomes of these secondary events are not known at the time the assessments are made, the assessment which takes into account the possible outcomes of these other events is called a conditional assessment. All combinations of the secondary event outcomes and their probabilities of occurrence (which must also be assessed) are considered. Then for each of these combinations or sets of conditions, the assessor makes a separate estimate of the probabilities of the outcomes of the main event known as "conditional probabilities."

```
                  ATTCK NOATK
CURRENT
PROBABILITY        10    90                      Assessment 1
LIKE. RATIO        1.6    1

IF THESE VALUES ARE CORRECT TYPE GO  GO

NORMALIZED PROBABILITIES -     15    85

           A REVIEW OF YOUR PROBABILITY ESTIMATES

                     ESTIMATE #
                  0     1
 MAINTAIN        ¯9   ¯14
 MIL.VIG.       ¯12   ¯14
 SIMPLE         ¯22   ¯22
 REINFRCD       ¯37   ¯35
```

```
                  ATTCK NOATK
CURRENT
PROBABILITY        10    90                      Assessment 2
LIKE. RATIO         4     1
IF THESE VALUES ARE CORRECT TYPE GO  GO
NORMALIZED PROBABILITIES -     31    69

           A REVIEW OF YOUR PROBABILITY ESTIMATES

                     ESTIMATE #
                  0     1
MAINTAIN         ¯9   ¯28
MIL.VIG.        ¯12   ¯19
SIMPLE          ¯22   ¯21
REINFRCD        ¯37   ¯31
```

(Characters typed by the user are underlined.)

Figure 5-1

PROBABILITIES REVISION BASED ON THE LIKELIHOOD RATIO DEMONSTRATED FOR THE WARSAW PACT ATTACK EXAMPLE. THE EFFECTS OF TWO DIFFERENT ASSESSMENTS OF THE LIKELIHOOD ARE SHOWN.

5.2.1 <u>A probability conditioned on one other event</u> - For example, suppose someone were to ask you to assess the probabilities of whether or not you will buy a new car next year. You might answer that it depends on the state of repair of your old car. At the present, you do not know what the outcome of this secondary event, "state of repair of your old car," will be, but you can list the different outcomes and then for each of these assess the probabilities that you would or would not buy a new car under those circumstances. For simplicity, suppose you consider only two possible outcomes for the state of your car, running well and frequent breakdowns. Suppose that the first state, running well, is the state that occurs. You might decide that in that case the probability of your buying a new car is only 0.20 (and so the probability of not buying is 0.80). On the other hand, given the information that you are having frequent breakdowns, you might assess the Buy/Don't Buy probabilities at 0.60 and 0.40. The assessments can be summarized in a conditional probability matrix as shown in Table 5-4.

In order to compute the unconditional probabilities of Buy and Don't Buy, each set of the conditional probabilities (each row) is first weighted by the probability of occurrence of that condition (row). These probabilities for the conditions can be assessed by the same person or by some other expert (your mechanic, for example). In this case (see Table 5-4B) we assume that the probabilities assessed are 0.70 that the old car will be running well and 0.30 that it will not. When these values are multiplied by the appropriate conditional probabilities, as shown in Table 5-4C, we obtain quantities known as the "joint" probabilities, meaning the probability that <u>both</u> the outcome indicated in the column and the outcome indicated in the row will occur. For instance, the 0.14 probability is the probability that next year your old car will be running well and you will nevertheless buy a new car. The final calculation needed to get the unconditional probability (sometimes called the marginal probability), for example, the unconditional probability of Buy, is to add up all the joint probabilities in the appropriate column. In this case, the probability of Buy is found to be 0.32 and of Don't Buy to be 0.68.

5.2.2 <u>A probability conditioned on more than one other event</u> - When an uncertain event is conditional on more than one secondary event, then the computations are more complicated. First, the relationship among the different events must be clearly specified. An "influence diagram" is one means of showing how the events are related. In an influence diagram, circles represent events, arrows represent the direction of influence. The main event whose outcome probabilities are to be computed is sometimes called the "target" event. The example of section 5.2.1 can be summarized by the influence diagram that follows.

A. Conditional Probability Matrix

CONDITIONAL PROBABILITY FOR NEW CAR PURCHASE

STATE OF OLD CAR	BUY	DON'T BUY
Running Well	0.20	0.80
Frequent Breakdowns	0.60	0.40

B. Probabilities of the Secondary Event (the Condition)

State of Old Car

Running Well:	0.70
Frequent Breakdowns:	0.30

C. Joint Probabilities

NEW CAR PURCHASE

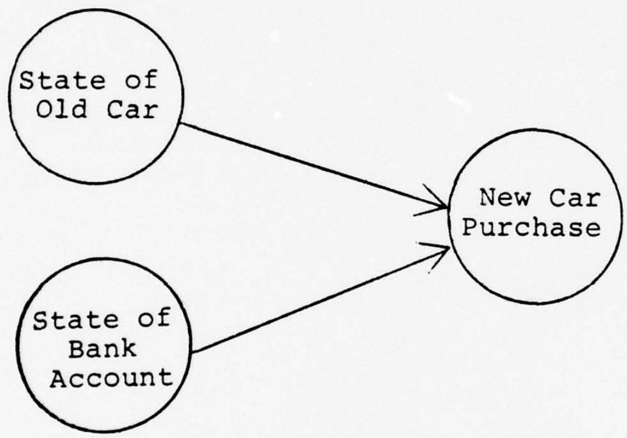
STATE OF OLD CAR	BUY	DON'T BUY
Running Well	0.70x0.20= 0.14	0.70x0.80= 0.56
Frequent Breakdowns	0.30x0.60= 0.18	0.30x0.40= 0.12
	0.32	0.68

D. Unconditional ("marginal") Probabilities

BUY	DON'T BUY
0.32	0.68

Table 5-4 – EXAMPLE OF CONDITIONAL PROBABILITY ASSESSMENTS

If another event is important to determining the outcome of the car purchase event, it can be added to the diagram. For instance, you might say that the state of your bank account next year (Broke, Normal, or Flush) is an important factor in influencing the purchase decision. The influence diagram then becomes



Now the conditional probabilities of Buy or Don't Buy must be assessed for all combinations of outcomes of the two influencing events. The conditional matrix to be filled is shown in Table 5-5.

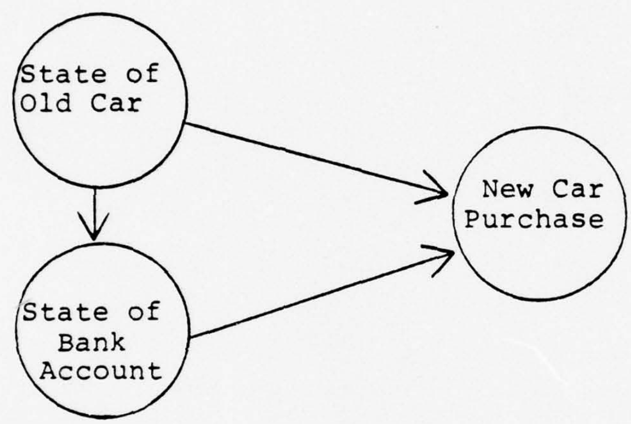
Conditional Probability

New Car Purchase

State of Car	State of Bank Account	Buy	Don't Buy
Running Well	Broke		
	Normal		
	Flush		
Frequent Breakdowns	Broke		
	Normal		
	Flush		

Table 5-5 — CONDITIONAL PROBABILITY MATRIX WITH TWO CONDITIONING EVENTS

Now six sets (rows) of conditional probabilities need to be assessed. After these are assessed, they are converted to joint probabilities (so that the columns can be totaled to find the unconditional probabilities of Buy and Don't Buy) by multiplying them by the probability of the corresponding combination of influencing events. When these influencing events are independent of each other, as is shown by the influence diagram, the probability of the combination is simply the product of the probabilities of its two components. The calculation is more difficult if there are more influencing events or if some are related to each other. For example, you might say that the state of your bank account depends in part on how much trouble you have had with your car. Then the influence diagram would look like this:



In the next section, we show how to carry out the conditional assessment for a more complicated, realistic example.

5.2.3 Civilian evacuation example - In Appendix C, the use of the technique for the rapid screening of decision options is demonstrated on another hypothetical example of military decision making. The general structure and the output of the problem, as produced by the computer program RAPOP, are shown in Appendix C. Here we shall briefly outline the problem and discuss in detail the description, or modeling, of the uncertain event portion of the analysis. This modeling requires the use of an influence diagram and the conditional assessment of probabilities from which joint and marginal probabilities are computed.

The decision to be made is on the deployment of U.S. naval forces in waters adjacent to Country C, given uncertainty about whether or not it will be necessary in the near future to evacuate U.S. nationals and others from Country C and, if so, how many people and under what conditions. The uncertain

event is defined to contain both the number of evacuees and the conditions of the evacuation. Five representative outcomes are considered:

- No evacuation,
- Permissive evacuation of 300 people,
- Permissive evacuation of 2000 people,
- Non-permissive evacuation of 2000 people, and
- Non-permissive evacuation of 6000 people.

Suppose a group of assessors were asked to assign probabilities to these five outcomes.

Discussion of the uncertainty among the group members could lead to a consensus that the factors influencing the evacuation event were the following:

- Whether or not the planned presidential election would be held in Country C and its outcome;
- Whether hostilities would increase or not;
- Whether an expected Country A invasion of Country C would take place north or south of the River; and
- Whether or not Country B would intervene.

The influence diagram in Figure 5-2 expresses the relationships among these factors. The diagram is interpreted as meaning that two events, the level of hostilities and whether or not Country B intervenes, have a direct effect upon the outcome of the uncertain event, evacuation. Furthermore, the election outcome, whether or not Country A invades, and the level of hostilities all have an indirect effect upon the evacuation outcome because they influence the probabilities of the two directly related events.

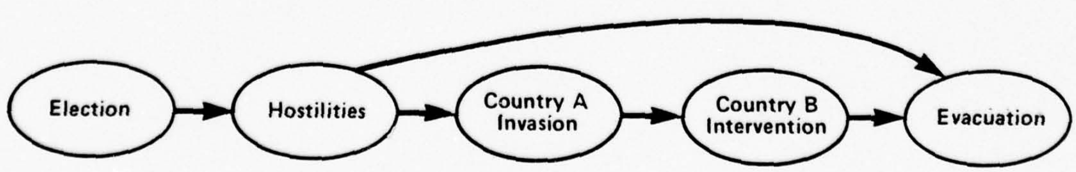


Figure 5-2

INFLUENCE DIAGRAM FOR THE CIVILIAN EVACUATION EXAMPLE

The probabilities of the main uncertain event, the evacuation, are assessed to be conditional upon the two directly influencing events by filling in the matrix shown in Table 5-6. For example, the first row is filled by assessing the probabilities for the five different evacuation outcomes given (or "conditional upon") the level of hostilities decreasing and there being no Country B intervention. Since these are conditional probabilities, the total of the probabilities in each row is 1.00. The values actually assessed in this exercise are given in Table 5-7.

Influencing Events			Conditional Probability					
Level of Hostilities	Country B Intervention		Uncertain Event: Evacuation (Number of People and Conditions of Evacuation)					
			1	2	3	4	5	
			No Evacuation	300 People Permissive	2000 People Permissive	2000 People Non-Permissive	6000 People Non-Permissive	
Decrease	No	1						1
	Yes	2						2
Status Quo	No	3						3
	Yes	4						4
Total City	No	5						5
	Yes	6						6
Beyond City	No	7						7
	Yes	8						8

Table 5-6 – MATRIX FOR THE ASSESSMENT OF CONDITIONAL PROBABILITIES FOR THE MAIN UNCERTAIN EVENT IN THE CIVILIAN EVACUATION EXAMPLE

On the basis of these values, some generalization can be deduced about the assessors' feelings about the outcome of the evacuation uncertainty. Looking only at the odd numbered rows (1, 3, 5, and 7), which all have as a condition no Country B intervention, we see that the probability of a large scale non-permissive evacuation (column 5) slowly increases with increasing hostility level (as would be expected). On the other hand, if Country B intervention is assumed, the probabilities for large-scale evacuation are much bigger. Furthermore, the evacuation probability, given this intervention, is the same if hostilities decrease or remain at the status quo (rows 2 and 4) or if hostilities increase to include all City or expand beyond City (rows 6 and 8).

Influencing Events			Conditional Probability					
Level of Hostilities	Country B Intervention		Uncertain Event: Evacuation (Number of People and Conditions of Evacuation)					
			1	2	3	4	5	
			No Evacuation	300 People Permissive	2000 People Permissive	2000 People Non-Permissive	6000 People Non-Permissive	
Decrease	No	1	1.00	0	0	0	0	1
	Yes	2	.10	.05	.25	.30	.30	2
Status Quo	No	3	.80	.05	.05	.10	0	3
	Yes	4	.10	.05	.25	.30	.30	4
Total City	No	5	.50	.05	.20	.15	.10	5
	Yes	6	.05	0	.10	.40	.45	6
Beyond City	No	7	.40	0	.20	.20	.20	7
	Yes	8	.05	0	.10	.40	.45	8

Table 5-7 — VALUES ASSESSED FOR THE CONDITIONAL PROBABILITIES OF EVACUATION

In order to convert this conditional probability matrix into a joint probability matrix whose columns can be totaled to compute the unconditional probabilities for each of the evacuation event outcomes, the probabilities of occurrence of the different combinations of outcomes of the directly influencing events are needed for use as weights. For the first of these influencing events, the unconditional probabilities, levels of hostilities can be computed by following the same procedure as was illustrated in the car purchase example of Table 5-4. The sum of the assessments conditional on the election outcomes are weighted by the unconditional election probabilities, as shown in Table 5-8. For the other influencing event, Country B intervention, the unconditional probabilities can be computed in a similar fashion, conforming to the relationships shown in the influence diagram. First, the intervention probability is assessed conditional on the location of the Country A invasion; then, this probability is weighted by the probabilities of the Country A activity (which in turn are found from an assessment conditional on the level of hostilities). These calculations are shown in a condensed form in Tables 5-9 and 5-10. The numbers in the cells in small type are the conditional probabilities. The numbers in large type on the margins are the unconditional probabilities while those in the cells also containing conditional probabilities are the joint probabilities (unconditional x conditional).

To find the probability of the hostility level-Country B intervention combinations, however, it is not sufficient to multiply together their unconditional probabilities because the Country B action also depends indirectly upon the hostility level. The easiest way to see how to calculate the required probabilities is by following through a probability tree diagram showing the order of occurrence of the uncertain events and their conditional probabilities.

In Figure 5-3, the probabilities of the levels of hostility are unconditional (obtained from Table 5-8D), the probabilities of the nodes for Country A invasion at different locations are conditional on the level of hostility shown on the particular branch that precedes the Country A invasion node. These probabilities are taken from the conditional probability matrix in Table 5-10. The conditional probabilities at each node add to 1.00, just as the rows of the conditional probability matrix add to 1.00. The probabilities of the Country B intervention nodes are taken from Table 5-9 and are conditional on the outcome of the Country A invasion event.

Each path through the probability tree represents a possible sequence of event outcomes. For example,

A. Conditional Probability

Elections	Level of Hostilities			
	Decrease	Status Quo	Total City	Beyond City
Held, Pro-Country A	.30	.20	.30	.20
Held, Not Pro-Country A	.30	.20	.30	.20
Cancelled, Country A Reasons	.05	.25	.40	.30
Cancelled, Other Reasons	.05	.20	.35	.40

B. Unconditional Probabilities for Election Outcome

Outcome	Probability
Elections held, result pro-Country A	.40
Elections held, result not pro-Country A	.10
Elections cancelled, due to Country A interference	.20
Elections cancelled, some other reasons	.30

C. Joint Probabilities

Elections	Level of Hostilities			
	Decrease	Status Quo	Total City	Beyond City
Held, Pro-Country A	.12	.08	.12	.08
Held, Not Pro-Country A	.02	.03	.03	.02
Cancelled, Country A Reasons	.01	.05	.08	.06
Cancelled, Other Reasons	.015	.06	.105	.12
	.17	.22	.33	.28

D. Unconditional Probabilities for Levels of Hostilities

Decrease	Status Quo	Total City	Beyond City
.17	.22	.33	.28

Table 5-8 — COMPUTATION OF THE PROBABILITIES OF DIFFERENT LEVELS OF HOSTILITIES

Level of Hostilities	Unconditional Probability (from Table 5-8D)	Country A Invasion Location Probabilities*	
		North	South
Decrease	.17	.95 .16	.05 .01
Status Quo	.22	.95 .21	.05 .01
Total City	.33	.95 .31	.05 .02
Beyond City	.28	.85 .23	.05 .05
Unconditional probability of Country A Invasion Location (the sum of the joint probabilities)		.91	.09

*Numbers in small type are probabilities conditional on the corresponding level of hostilities. Numbers in large type are the joint probabilities of both the invasion location and hostilities level.

Table 5-9 – COMPUTATION OF THE UNCONDITIONAL PROBABILITIES OF COUNTRY A INVASION NORTH AND SOUTH OF THE RIVER

Location of Country A Invasion	Unconditional Probability (from Table 5-9)	Country B Intervention Probabilities*	
		Intervention	No Intervention
North of the River	.91	.10 .09	.90 .82
South of the River	.09	.90 .08	.10 .01
Unconditional Probability of Country B Intervention (the sum of the joint probabilities)		.17	.83

* Numbers in small type are the probabilities conditional on the corresponding location of the Country A invasion. Numbers in large type are the joint probabilities of both the invasion location and the Country B action

Table 5-10 – COMPUTATION OF THE UNCONDITIONAL PROBABILITIES OF COUNTRY B INTERVENTION

the uppermost path represents a decrease in level of hostilities, a Country A invasion north of the River, and no Country B intervention. The probability of any path is calculated simply by multiplying together all the probabilities along the path. The probability of the uppermost sequence of events is:

$$0.17 \times 0.95 \times 0.90 = 0.145.$$

The probabilities of the other paths are computed in the same manner and are shown in Figure 5-3 under the heading "End Point Probabilities."

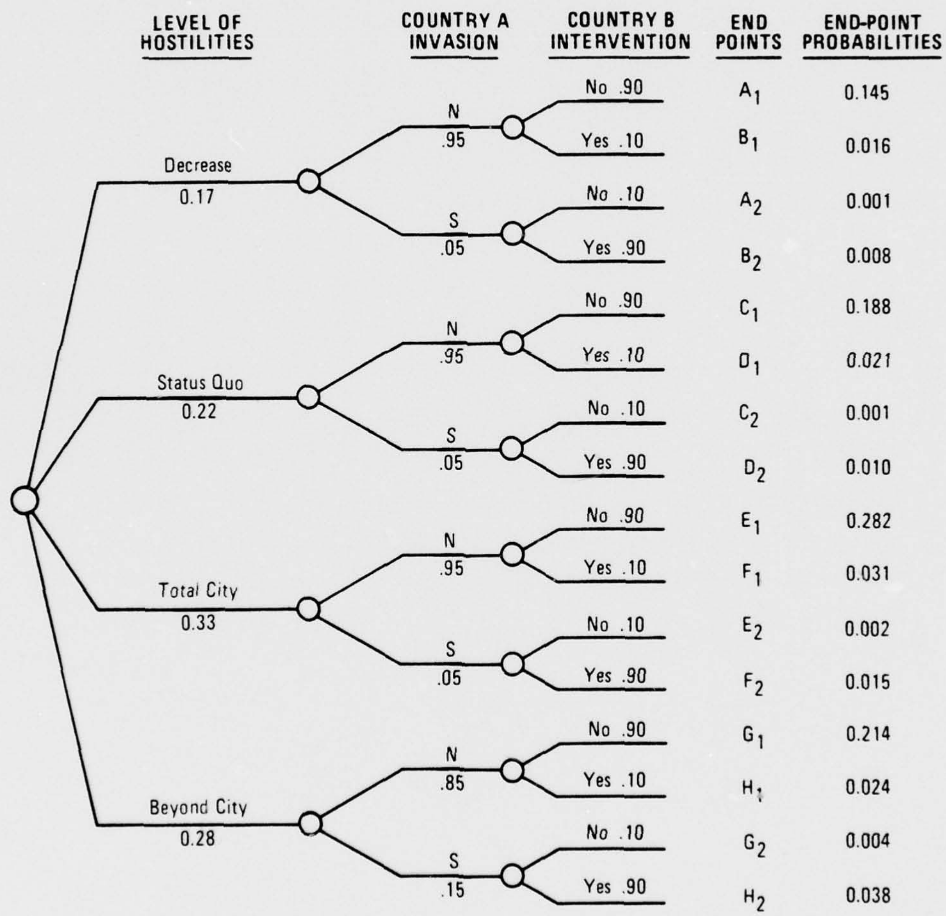


Figure 5-3

PROBABILITY TREE FOR THE COMPUTATION OF THE PROBABILITIES OF DIFFERENT COMBINATIONS OF LEVELS OF HOSTILITIES WITH COUNTRY B ACTION

The purpose of the probability tree, it will be recalled, is to generate the probabilities of occurrence of the combinations of hostility level and Country B action outcomes for use as weighting factors in the conditional probability of evacuation matrix in Table 5-7. The first combination is decrease in hostilities and no Country B intervention. This combination of outcomes occurs on two paths of the probability tree, those whose end points are labeled A1 and A2. In one case, the combination occurs with the assumption of a Country A invasion north of the River, in the other case with the assumption of a Country A invasion south of the River. The total probability of the combination hostilities decrease, and Country B does not intervene is the sum of the probabilities of these two paths, or

$$0.145 + 0.001 = 0.146$$

or, rounded off to two decimal places,

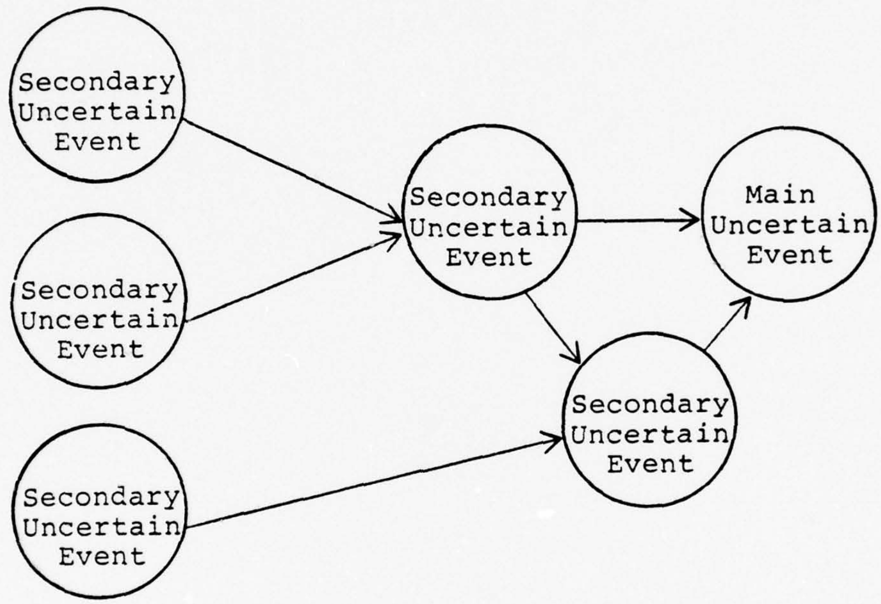
$$0.15.$$

The next combination considered, hostilities decrease and Country B does intervene, occurs for paths labeled B1 and B2. Its probability is computed in the same way. Table 5-11A shows all the required probability values. In Table 5-11B, these probabilities have been applied as weights to obtain the joint probability matrix of hostility-intervention and evacuation outcome, and in Table 5-11C, the unconditional evacuation outcome probabilities are shown.

5.2.4 Discussion - The reason for going through this civilian evacuation example in detail is to demonstrate how to accommodate, in the matrix format, decision problems having uncertain events whose probability of occurrence is more complicated to assess than that of the Warsaw Pact attack example. This procedure for modeling the uncertainty can be summarized as three steps:

- Draw the influence diagram to show relationship among the main and secondary uncertain events;
- Assess the conditional probabilities in the order and manner specified by the influence diagram; and
- Where necessary, compute the unconditional probabilities.

Obviously, the drawing of the influence diagram and the calculation of probabilities require care and some experience. The present version of the computer aid, the OPINT program, provides considerable help in carrying out this task. The user draws an influence diagram describing the uncertainty relationships in the particular problem being studied. A number of secondary events can be considered, and each event can have up to two other events influencing it. The probability model shown below, for example, is a feasible one for solution by the computer program.



In practice, however, the influence diagram should be kept as simple as possible without sacrificing realism. The description of the influence diagram is fed into the computer. The computer program then generates requests for all the necessary conditional probabilities. The user makes conditional assessments of the probability and types them into the computer. The final and most complicated step, the computation of the unconditional probabilities, is then carried out automatically by the computer program. The unconditional probabilities of the different outcomes of the main uncertain event are displayed.

A sensitivity analysis can be carried out to test how the optimal decision option, measured in terms of expected regret, changes with changes in these probabilities. This analysis is shown in Appendix C along with the detailed discussion of the decision options and the value dimensions.

A. Probability Values

Outcome Combination		Probability *
Hostility Level	Country B Intervention	
Decrease	No	0.145 + 0.001 = 0.15
	Yes	0.016 + 0.008 = 0.02
Status Quo	No	0.188 + 0.001 = 0.19
	Yes	0.021 + 0.010 = 0.03
Total City	No	0.282 + 0.002 = 0.28
	Yes	0.031 + 0.015 = 0.05
Beyond City	No	0.214 + 0.004 = 0.22
	Yes	0.024 + 0.038 = 0.06

* Rounded off to two decimal places.

B. Joint Probabilities

Influencing Events		JOINT PROBABILITY				
		Uncertain Event: Evacuation (Number of People and Conditions of Evacuation)				
Level of Hostilities	Country B Inter-vention	No Evacuation	300 People Permissive	2000 People Permissive	2000 People Non-Permissive	6000 People Non-Permissive
Decrease	No	.15	0	0	0	0
	Yes	.002	.001	.006	.007	.007
Status Quo	No	.15	.01	.01	.02	0
	Yes	.003	.002	.008	.009	.009
Total City	No	.14	.01	.06	.04	.03
	Yes	.002	0	.005	.018	.021
Beyond City	No	.087	0	.044	.044	.044
	Yes	.003	0	.006	.025	.028

C. Unconditional Probabilities of Evacuation

	No	300 P	2000 P	2000 NP	6000 NP
Probability:	.54	.02	.14	.16	.14

Table 5-11 – CALCULATION OF UNCONDITIONAL PROBABILITIES OF EVACUATION

6.0 EVALUATION OF THE RAPID SCREENING METHOD

The usefulness of this computer-aided method for the rapid screening of decision options can be judged by considering its various strengths and weaknesses. The main strengths of the procedure stem from the virtues generally claimed by decision analysis--quantification, normativeness, and communicability--all incorporated in a procedure that, compared to a full decision analysis, is relatively simple and rapid. Some of the weaknessses of the method, however, can also be attributed to this simplification which, at worst, may make the problem solved by the analysis so different from the actual decision problem faced that the solution is of no practical value.

6.1 Strengths

Like the standard decision-analytic procedure, this method for the rapid screening of decision options requires that the decision maker systematically list all decision options and event outcomes and express quantitatively the probability of occurrence for each outcome and the value of the different outcomes on several dimensions. This information is then processed mathematically to determine the optimal decision option and, through a sensitivity analysis, to reveal the assumptions and assessments which are critical to the choice of the best decision option. Such a formal procedure for decision making under uncertainty is generally considered to be superior to more intuitive methods where some factors may be overlooked or incorrectly weighted when their importance to the final decision is considered. Besides identifying critical factors for further study and promising on the average and in the long run to give better decision making, the rapid screening procedure also promotes understanding of the problem both for an individual decision maker and within a group of decision makers. This increase in understanding occurs because the factors or events having an effect upon the probabilities must be enumerated during the probability assessment and because the dimensions and importance of the outcome values must be made explicit. Communication is improved among the people who are party to the decision; people with differing opinions can, by using the computer aid, test the effect of their ideas on the final output; and, consequently, everyone's confidence in the correctness of (or at least the justification for) the selected decision option should be high.

The points cited above show how decision making for a particular problem may be improved by using the rapid screening method. In addition, the method has some usefulness as an introduction to the concepts of decision analysis and as

a training device in the application of these concepts. A user's experience with one problem may in this way help to make the solution of future problems better and easier.

6.2 Weaknesses

6.2.1 Simplifications - The simplified format of the rapid screening method differs from the standard decision analysis format in that (1) only one decision node is allowed, followed by only one event node and (2) the probabilities of the different event outcomes are always independent of the action taken. If these implications are too restrictive, then the solution to the simplified problem (its best decision option) may not be a good approximation to the solution to the real (unsimplified) problem. For example, in the Warsaw Pact attack case, the assumption is made that the probabilities of attack versus no attack (initially assessed as 0.10 and 0.90) are independent of the decision option taken by NATO. In other words, whether NATO maintains the status quo or goes so far as to order a reinforced alert will have no effect upon the Pact's decision to attack or not. (Our interpretation of the 0.10 and 0.90 probabilities is then as follows: the Pact has already decided either to attack or not. NATO actions [within the range of options considered] will not change its decision. NATO does not know what the Pact's decision is but believes that there is a 0.10 probability that the intention is to attack and a 0.90 probability that it is not to attack.) If this assumption of independence of probabilities is incorrect, then the expected values of the regret under different decision options should be obtained by multiplying the values in the combined valuation regret matrix by different probabilities (newly assessed to account for the dependency) depending on which row (option) is being considered. This change in the calculation would generally result in different expected values and, consequently, might cause the optimal option (defined as the option having the smallest expected regret) to change.

The requirement of the simplified format that the problem has only one immediate decision node and one uncertain event node has the effect of eliminating the ability of the analysis to represent accurately a problem where there may be a sequence of decisions to be made. In the Warsaw Pact attack example, for instance, the probability graph (Figure 4-1) shows which decision is optimal for all possible attack probabilities from 0.0 to 1.0. If the probability is 0.50, for example, then the optimal decision is simple alert. It does not necessarily follow, however, that, if NATO actually went first to military vigilance on the basis of some data leading the probability of attack to be assessed at 0.30 (say) and then subsequently received

information leading the probability to be revised to 0.50, simple alert would still be the optional decision. This is because the regret matrices showing the values on different dimensions of the various options were assessed with the implicit assumption that the current status was no extra-ordinary alert position. If the status quo were simple alert, these values or their weights might be different.

6.2.2 Value assessments: payoff versus regret - Another possible weakness of the method is that people will have a great deal of difficulty in assessing the outcome values on the artificial scales used here. If these assessments are not done coherently, then the output of the entire analysis is called into question.

In the examples shown here, the value within each dimension of a particular combination of decision option and event outcome was assessed, not by comparing all combinations to each other (payoff measures) on some absolute scale, but by taking each event outcome separately and, within that outcome column, assessing the regret resulting from making a non-optimal decision compared with the best possible decision under that outcome. One of the reasons for this approach is that, when the values of the options under one outcome are clustered at one end of the payoff scale and those under another outcome at the opposite end, the assessor may have difficulty in discriminating among the points in each cluster. For example, with two outcomes and four options, the payoff values assessed might be 0, 1, 2, 3 under one outcome and 100, 99, 98, 97 under the other. This lack of discrimination within a column is overcome by the technique of regret assessment which emphasizes comparisons within a column. Another reason for assessing regrets is that some assessors find it quite easy to answer questions phrased in regret terms (e.g., "Is it a bigger mistake in political cost terms to have failed to go to reinforced alert if there is an attack or to have mistakenly gone on reinforced alert when no attack occurs?").

However, despite these advantages of the regret assessment, this method may have some drawbacks. It may be that assessors have difficulty in keeping in mind what is meant by the regret measurement (namely, the comparison of a considered option to the optimal option) when using values of one column as a basis for getting those of another column or, what may be even more difficult, when comparing a column in one dimension to a column in another dimension to determine importance weights. The difficulty anticipated here is that an assessor will not be able to keep in mind simultaneously the three or four necessary factors. For intra-matrix comparisons, these factors are the optimal option and the considered option under one outcome versus the optimal

option and the considered option under another outcome. For inter-matrix comparisons, the factors which may differ are the optimal option in each matrix, the considered option in each matrix, the outcome considered in each matrix, and the dimension of value. An assessor who has difficulty dealing with this complexity may initially assess values in terms of regret but then treat these as if they were payoffs in later stages of the assessment. For example, after the expert has assessed the regret matrices for military risk and for political cost in the Warsaw Pact attack exercise, he is asked, "Which is a worse mistake (and how much worse), -100 under military risk or -100 under political cost?" Rather than considering this question in regret terms, where "mistake" means regret at having chosen the wrong option when you could have chosen the optimal one, the assessor may respond on the basis of payoff, as if the question were, "Which option-outcome combination is worse (and how much), the military risk of an attack when you are in status quo readiness or the political cost under the same circumstances?"

This difficulty with regret assessments will be the object of further study. Three possible ways of testing for its existence and overcoming the confusion are:

- Assessing the value matrices and their importance weights both in terms of payoffs and of regrets. These assessments would be made at separate times and the results compared by looking at the regrets assessed directly and those computed from the payoffs;
- Presenting the questions used to elicit the regret assessments as paired comparisons, <u>without</u> displaying the whole matrix to the assessor; and
- Asking the assessor to justify each regret assessment with a few sentences explaining <u>why</u> one mistake is comparable to, or a certain amount worse than, another. By listening to these explanations, the elicitor may be able to tell whether the assessor is correctly considering the regret value rather than payoffs.

For the regret assessments presented in the examples of this paper, the third of these approaches was tried.

6.3 Conclusions

The overall experience of Decisions and Designs, Incorporated with this simplified approach to the rapid screening of decision options is quite positive. The solutions to the

problems to which it has been applied are seen as plausible by the users of the method in light of their explicit probability and value assessments. Furthermore, the discussion of these probabilities and values has improved communication among different parties to the decision. The users are also enthusiastic about their ability to modify by themselves both the structure of the problem and its inputs.

However, before inexperienced users attempt to apply this computer-aided method for the rapid screening of options, completely on their own, the users should receive instruction in:

- The formulation of problems, to ensure that the requirement of probability independence between options and outcomes is met;
- The construction of influence diagrams for computing probabilities that are related to several uncertain events; and
- The procedures for assessing regret values and weights to ensure that these are thoroughly understood.

APPENDIX A

COMPARISON OF STANDARD AND MATRIX FORMATS

A.1 Standard Format Using a Decision Tree

The standard format of the presentation of decision analysis problems is shown in Figure A-1. In the particular sample problem shown here, there is a primary decision node (indicated by a square in the diagram) with three possible options "A," "B," and "C." Each of these options is followed by an uncertain event (indicated by a circle) having two possible outcomes. The probabilities of each of these two outcomes and the outcomes themselves can vary depending on which option, A, B, or C, is taken. Some of the outcomes Y, Z, V, and U, are followed by another decision node with two alternatives or options shown, and for one of these alternatives, K, there is yet another uncertain event having, in this example, two outcomes. Each of the end-points of this tree corresponds to a different path through the tree and a different combination of decision options and outcomes of uncertain events. The value to the decision maker of being at one or another of these end-points will vary from end-point to end-point since the decision is not otherwise worth considering. For many problems, the value to the decision maker of any end-point consists of several factors. This feature is incorporated into the analysis by saying that an end-point value can be measured along a number of different dimensions, shown in Figure A-1 by the set of V values. Decision analysis provides a technique for converting each set of V values into a single measure, U, of the utility. Choosing the decisions to be considered, the uncertain events and their outcomes, and the dimensions on which the value of end-points can be measured, are steps in the decision analysis which are generally called, by the users of this technique, the "structuring" of the decision problem.[1] Estimating the probabilities of the outcomes of different uncertain events, on the other hand, and determining the value on each dimension of a particular end-point are referred to as the preparation of the input to the analysis.

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[1] The numbers of decision nodes, of options at each node, of uncertain events, and of outcomes of each event depend on the specific problem being studied.

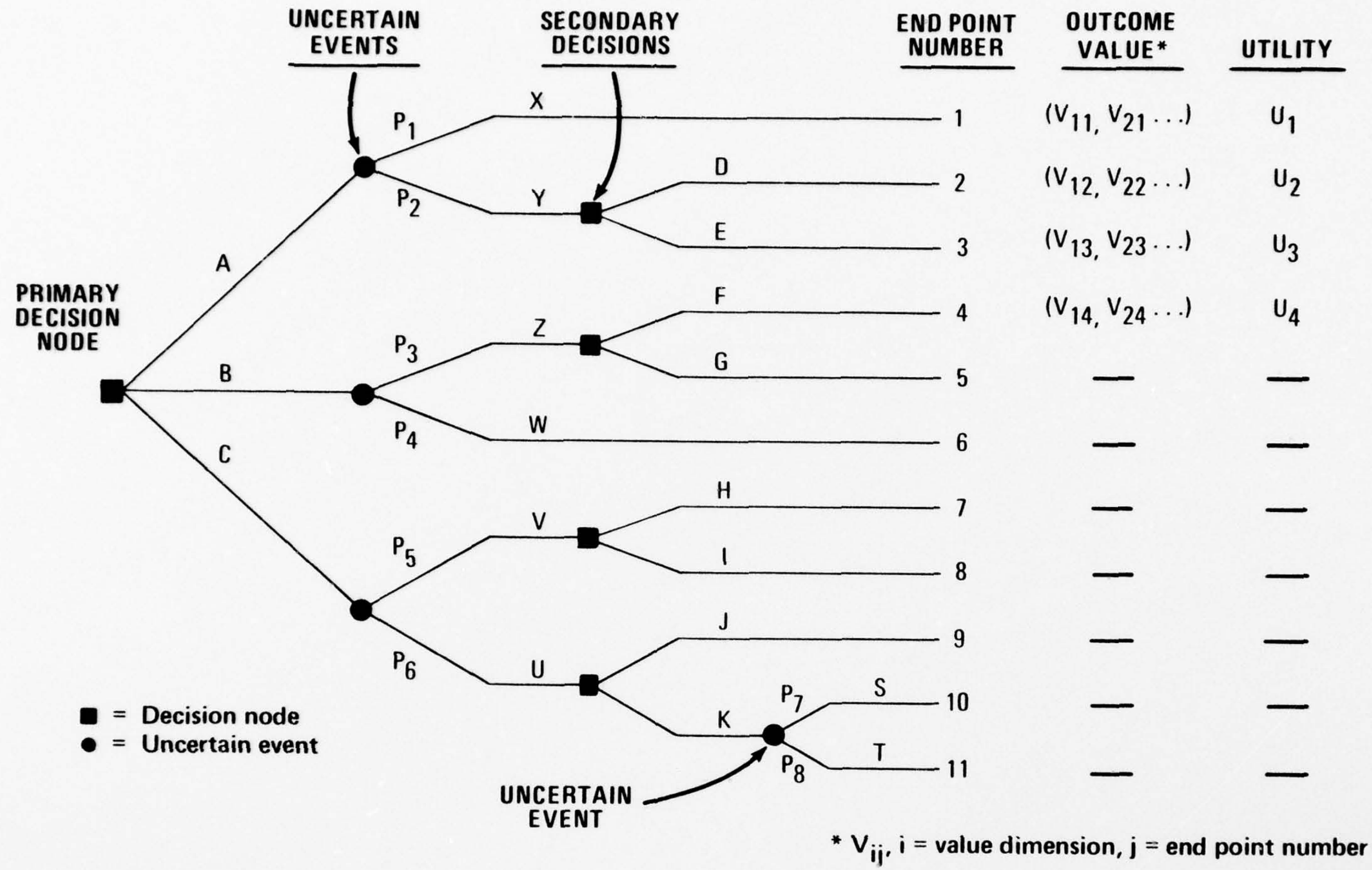

Figure A-1

DECISION ANALYSIS FORMAT FOR A SAMPLE PROBLEM

A.2 Simplified Format Using a Decision Tree

A simplified decision analysis format is shown in Figure A-2. Here there is only a single decision node followed by a single uncertain event node. Furthermore, the probabilities of the different outcomes of the uncertain event (in this case, three outcomes are shown) are the same, regardless of which decision option is taken. Any end-point position of this simplified tree can still be valued on many dimensions and then summarized into a single utility figure. This simplified formulation of the decision is necessary in order to use the set of computer programs which are presented in this paper as a decision aid for the rapid evaluation of decision options. If a decision problem is naturally structured as shown in Figure A-2, or if a more complicated formulation such as that of Figure A-1 can be simplified to the Figure A-2 format without too great a loss of realism, then the decision problem is a candidate for study by this rapid screening procedure. In some cases, it may be possible to go from the first formulation to the more simplified formulation by omitting some of the options at the initial decision node, omitting some of the subsequent decision points and redefining the uncertain events in such a way that their probabilities of occurrence are independent of the action that proceeds them.[2]

A.3 Basic Matrix Format

The simplified decision tree contains all the information needed to carry out an approximate analysis of the candidate problem. Since there is only one decision node and one uncertain event, an alternative way of displaying this information is in the form of a table or matrix,[3] as is described in Section 2.3 of the text. The rows represent the alternative decision options and the columns of the matrix represent the different possible outcomes of the uncertain event. Each cell represents an option-outcome combination (and corresponds

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[2] An example of a problem where the uncertain event is recast so that the outcome probabilities are independent of the option chosen is presented in Judith Selvidge, Structuring a Decision Problem for Solution by the Rapid-Screening-of-Decision-Options Method, Technical Report (McLean, Va.: Decisions and Designs, Inc., forthcoming).

[3] Sometimes called, in elementary decision analysis, the "pay-off" or "opportunity loss" table. This presentation is referred to as the "normal" form of the analysis as contrasted to the "extensive" form using trees.

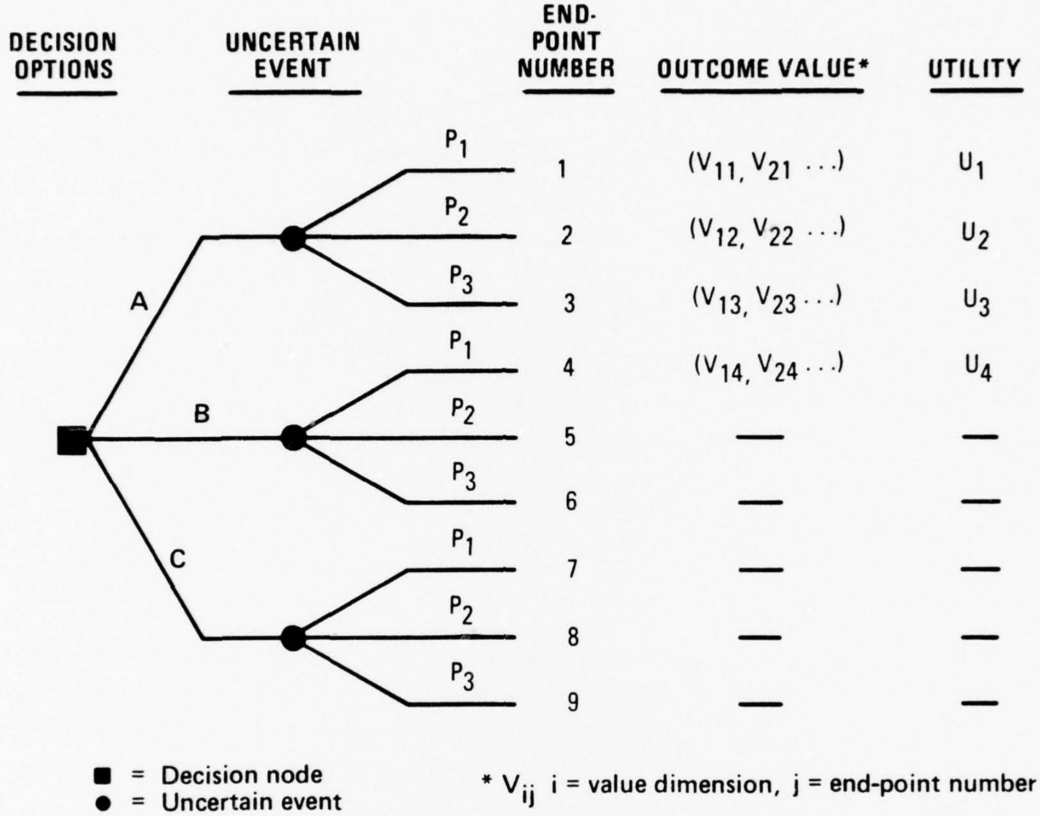

Figure A-2
SIMPLIFIED DECISION ANALYSIS FORMAT

to an end-point in the decision tree). The cells contain the value, measured on some dimension, of the particular option-outcome combination. There is a separate matrix for each value dimension.

Table A-1 assumes that there are three different dimensions of value of interest and shows how the decision sketched in Figure A-2 appears in the basic matrix format.

The principal advantages of presenting decision problems in the basic matrix format are, one, people inexperienced in decision analysis seem to understand the matrix presentation more easily than the decision tree format and, two, a problem described in the matrix format can be analyzed rapidly on a portable computer using the "OPINT" program described in this paper. These advantages are discussed in Sections 1.0, 2.3, and 6.1.

VALUE* DIMENSIONS

Value 1

Uncertain Event Outcomes

DECISION OPTIONS	1	2	3
A	V_{1A1}	V_{1A2}	V_{1A3}
B	V_{1B1}	"	"
C	V_{1C1}	"	"

Value 2

Uncertain Event Outcomes

	1	2	3
A	V_{2A1}	"	"
B	"	"	"
C	"	"	"

Value 3

Uncertain Event Outcomes

	1	2	3
A	V_{3A1}	"	"
B	"	"	"
C	"	"	"

*V_{ijk}; i = value dimension
j = decision option
k = event outcome

PROBABILITIES FOR
THE UNCERTAIN EVENT

OUTCOMES

1	2	3	
P_1	P_2	P_3	Total 1.00

Table A-1 – THE SIMPLIFIED DECISION PROBLEM OF FIGURE A-2 PRESENTED IN THE MATRIX FORMAT

As an analysis is being carried out on a problem expressed in the matrix format, two rather technical advantages are apparent. The first arises during the assessment of the value on various dimensions of the option-outcome combinations. (See Sections 3.2.2 through 3.2.4.) Some decision analysts believe that when artificial scales are employed to measure value on dimensions like "political cost," users can more easily assess the value in terms of regret rather than payoffs or losses. A regret assessment, it will be recalled, involves considering a <u>single outcome</u> of the event in combination with all the different possible decision options. The best option-outcome combination among these is then given a value of zero (no regret) and all other combinations are rated according to how much worse the considered combination is compared to the best combination. Under the decision tree format, this would involve, for instance, for the first event outcome, looking at end-points 1, 4, and 7 (and, for the first value dimension, values V_{11}, V_{14}, V_{17}) on the tree shown in Figure A-2. The matrix formulation facilitates such comparisons since the option-outcome combinations to be considered together are all in one column of the matrix rather than being scattered around in a tree.

The other technical advantage of the basic matrix arises from the requirement that the outcome probabilities be independent of the decision options. When the solution of the analysis, measured in terms of the expected value for each decision option, is tested for sensitivity to changes in the values of the outcome probabilities, the effect of such changes can be shown graphically (see Section 4.3).

APPENDIX B

DATA AND UPDATED PROBABILITIES FOR THE WARSAW PACT ATTACK EXAMPLE

The Warsaw Pact attack example is an exercise in the structuring of a decision problem to conform to the basic matrix format, the assessment of a multi-attributed value function expressed in terms of regret, and the assessment and updating of probability values.

This appendix presents the data that were prepared and used as the basis for the probability assessments. Table B-1 shows the probabilities initially assessed when only the background information (Table 5-1 in Section 5.1.1) was available. The new information and the successively revised probabilities are shown in Tables B-2 through B-13 (Table B-13 is a summary of all the successive probabilities).

These probability revisions were made by a method[1] that combines features of the direct assessment and the Bayes' theorem methods mentioned in Section 5.1.2. The method used was basically as follows: The person making the assessment was shown each new datum and asked to make a direct revision of the probability. After the probabilities had been revised in this manner for several data points, the assessor was shown graphically what these revisions implied about the likelihood ratios of different data. (This information can be computed since, just as one can go from a likelihood ratio to the revised probability, one can calculate backwards from the revised probability to obtain the likelihood.) The assessor was then asked if these likelihoods, when compared to one another, made sense. For example, this kind of question was posed: "Your likelihood ratio (probability of this datum if there were an attack versus probability of this datum if there were no attack) is twice as large for datum A as for datum C. This implies that you think datum A is twice as strong an indicator as datum C. Is that implication a correct reflection of your feelings?" In cases where the assessor was not comfortable with the implications of the likelihood values, the revised probabilities were adjusted until acceptable likelihoods were obtained. The values of the probabilities shown in Tables B-2 through B-13 are the average values produced by a number of intelligence analysts, each following the procedure outlined above.

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[1]For a more detailed explanation of this technique, see Cameron R. Peterson et al., "Inference from Evidence: Bayes' Theorem," in their Handbook for Decision Analysis (McLean, Va.: Decisions and Designs, Inc., 1973).

DATA		PROBABILITY ASSESSMENT	
		PACT ATTACK	NO PACT ATTACK
INITIAL	THROUGH 1 FEB	10	90

Table B-1 — INITIAL PROBABILITY ASSESSMENT

FEBRUARY 2

O GERMANY, ITALY, FRANCE AND BELGIUM ALL REPORT AN INCREASE IN THE NUMBER OF INCIDENTS NEAR MILITARY FACILITIES THAT CAN BE RELATED FOR FOREIGN-INSPIRED SUBVERSIVE ACTIVITIES, PARTICULARLY DURING THE PAST 48 HOURS.

FEBRUARY 3

O SOVIETS WARN U.S. THAT SIXTH FLEET IS OPERATING DANGEROUSLY IN THE MEDITERRANEAN AND INTERFERING WITH SOVIET FLEET OPERATIONS.

O WARSAW PACT MEDICAL PERSONNEL ARE ORDERED TO THEIR ACTIVE DUTY UNITS TO PARTICIPATE IN LARGE-SCALE EXERCISE. LITTLE MEDICAL PLAY HAS BEEN NOTED IN PREVIOUS EXERCISES.

O AN ECONOMIC MISSION REPRESENTING TWO NATO COUNTRIES IS WELCOMED IN MOSCOW.

FEBRUARY 4

O GERMAN SECURITY PERSONNEL REPORT PICKING UP A SOVIET UNDERCOVER AGENT NEWLY ASSIGNED AND APPARENTLY WITH THE MISSION OF INTERFERING WITH NATO COMMUNICATIONS FACILITIES.

Table B-2 — DATUM 1

DATA		PROBABILITY ASSESSMENT	
		PACT ATTACK	NO PACT ATTACK
INITIAL	THROUGH 1 FEB	10	90
DATUM 1	2 FEB - 4 FEB	15	85

Table B-3 — REVISED ASSESSMENT 1

FEBRUARY 5

O THE U.K. REPORTS A USUALLY RELIABLE SOURCE HAS INFORMATION THAT SOME SOVIET MERCHANT VESSELS ARE BEING FITTED WITH GUNS. AGENT BELIEVES GUNS HAVE BOTH A SURFACE-TO-SURFACE AND SURFACE-TO-AIR CAPABILITY. DESCRIPTION OF GUNS INDICATES THAT QUAD-MOUNTED 12MM, DUAL-MOUNTED 14MM, AND 37MM GUNS ARE PREDOMINANT.

FEBRUARY 6

O INCREASED STOCKING OF WARSAW PACT AMMO DUMPS, IN EXCESS OF ANNOUNCED EXERCISE REQUIREMENTS IS REPORTED BY ONE OF THE NATO NATION'S NATIONAL INTELLIGENCE AGENCIES.

O PROPAGANDA CONTINUES WITH THE TENOR BEING THAT EUROPEAN NATIONS SHOULD QUIT BEING U.S. PUPPETS, THAT THEY COULD NOT DEPEND ON U.S., AND THAT PEACE COULD BE MAINTAINED THROUGH INCREASED EUROPEAN COOPERATION WITH THE USSR AND REDUCED RELATIONS WITH THE U.S.

FEBRUARY 7

O MOSCOW ANNOUNCED THAT IN ADDITION TO A REDUCTION IN CONSUMER GOODS, INCREASED ENERGY REQUIREMENTS MEAN LESS POL FOR CONSUMER-RELATED INDUSTRIES.

FEBRUARY 8

O U.S. REPORTS A BUILD-UP OF RUSSIAN SUBMARINES IN BOTH THE ATLANTIC AND PACIFIC.

O USLM REPORTS SOVIETS INCREASING FIELD MEDICAL FACILITIES IN THE GDR EXERCISE AREA. ADDITIONAL MEDICAL UNITS ARE ASSIGNED TO THE EXERCISE.

O ARTICLES HINT AT POSSIBLE INVITATION TO SOME SENIOR WESTERN MILITARY MEDICAL PERSONNEL TO VISIT THE UPCOMING EXERCISE.

FEBRUARY 9

O SEVERAL NEW MILITARY CONSTRUCTION PROJECTS IN EXERCISE AREA, IN EXCESS OF WHAT HAS BEEN OBSERVED FOR PREVIOUS EXERCISES, ARE REPORTED BY GERMAN NATIONAL INTELLIGENCE SOURCE.

O SOVIETS ANNOUNCE WORK UNDER PROGRESS FOR CONSTRUCTION OF TEMPORARY FIELD HEADQUARTERS AND LOGISTIC SUPPORT AREAS FOR EXERCISE.

Table B-4 – DATUM 2

- UNUSUALLY LARGE NUMBER OF TRUCKS CARRYING MILITARY SUPPLIES ARE NOTED BY CORRIDOR AIRCRAFT FLYING TO AND FROM BERLIN.

- FEWER SOVIET COMMERCIAL VESSELS ARE NOTED IN WESTERN PORTS. IT APPEARS THAT MORE THAN USUAL NUMBERS OF SOVIET COMMERCIAL VESSELS ARE IN SOVIET PORTS.

- SACEUR HAS INFORMATION FROM AN UNEVALUATED SOURCE THAT THE USSR HAS ORDERED SOME MOBILIZATION, THE DEGREE UNKNOWN.

- NATO INTELLIGENCE HAS RECEIVED AN UNCONFIRMED REPORT OF UNUSUAL ACTIVITY AT A DISPERSAL AIRFIELD IN POLAND.

Table B-4 – DATUM 2 (continued)

DATA		PROBABILITY ASSESSMENT	
		PACT ATTACK	NO PACT ATTACK
INITIAL	THROUGH 1 FEB	.10	.90
DATUM 1	2 FEB - 4 FEB	.15	.85
DATUM 2	5 FEB - 9 FEB	.35	.65

Table B-5 – REVISED ASSESSMENT 2

FEBRUARY 10

- O MOSCOW ANNOUNCES 100% SUPPORT FOR COMING PACT EXERCISE IN ORDER TO PLAY THE GAME AS REALISTICALLY AS POSSIBLE. THE USSR HAS CANCELLED SOME MILITARY LEAVES AND IS ORDERING PERSONNEL INVOLVED TO RETURN TO THEIR UNITS.

- O RUSSIA THREATENS DANISH AND NORWEGIAN SHIPPING AND RECALLS THE SOVIET AMBASSADORS FROM NORWAY, SWEDEN, FINLAND, AND DENMARK TO MOSCOW FOR AN UNKNOWN PERIOD OF TIME.

FEBRUARY 11

- O MOSCOW ANTI-U.S. AND ANTI-WESTERN PROPAGANDA REACHES A NEW PEAK FOR RECENT YEARS.

- O NORTHERN NATO NATIONS ARE WARNED TO KEEP NAVAL UNITS OUT OF EASTERN BALTIC OR FACE HAVING THEM SEIZED.

FEBRUARY 12

- O U.S. AND U.K. MILITARY ATTACHES ARE ACCUSED OF SPYING; TWO MILITARY ATTACHES ARE ARRESTED BY SOVIETS. ALL OTHER U.S. PERSONNEL ARE RESTRICTED TO EMBASSY AREA OF MOSCOW.

- O HEAVY PACT TROOP MOVEMENTS ARE NOTED COMING THROUGH WESTERN MILITARY DISTRICTS OF USSR TOWARD FRONT-LINE EXERCISE AREA.

FEBRUARY 13

- O PACT MILITARY LEADERS ASSEMBLE FOR MEETING IN MOSCOW. PRAVDA STATES MEETING IS IN CONNECTION WITH EXERCISE PLAN. SUCH HIGH-LEVEL REVIEW HAS NOT BEEN OBSERVED FOR PREVIOUS EXERCISES.

- O WESTERN NEWSPAPERS REPORT THAT POPULACE IN LARGE CITIES OF WARSAW PACT NATIONS HAVE BEEN TOLD THAT THEY TOO WILL BE INVOLVED IN THIS YEAR'S PACT EXERCISE, THOUGH THE EXTENT HAD NOT YET BEEN DETERMINED. HOWEVER, TO BE READY, CIVIL DEFENSE ALERTS AND RELATED ACTIVITY WILL BE INCREASED.

Table B-6 – DATUM 3

DATA		PROBABILITY ASSESSMENT	
		PACT ATTACK	NO PACT ATTACK
INITIAL	THROUGH 1 FEB	.10	.90
DATUM 1	2 FEB - 4 FEB	.15	.85
DATUM 2	5 FEB - 9 FEB	.35	.65
DATUM 3	10 FEB - 13 FEB	.60	.40

Table B-7 — REVISED ASSESSMENT 3

FEBRUARY 14

- O GERMAN INTELLIGENCE REPORTS A GREATLY INCREASED NUMBER OF SOVIET TECHNICIANS CURRENTLY ARRIVING IN POLAND, HUNGARY, AND CZECHOSLOVAKIA.
- O FRENCH AMBASSADOR TO RUSSIA IS CALLED TO KREMLIN AND MADE AWARE OF SOVIET'S CONCERN FOR CERTAIN MILITARY RELATED ACTIVITIES THEY HAVE OBSERVED IN FRANCE AND INTERPRETED AS INCREASED MILITARY READINESS ACTIONS.
- O BRITISH REPORT CONFIRMS EARLIER REPORT OF FITTING OF SOVIET COMMERCIAL VESSELS WITH GUNS AND ALSO REPORTS SOVIET NAVY WAS INVOLVED IN PRACTICE LAYING OF A SUBMARINE NET ACROSS HARBOR IN VLADIVOSTOK AND MURMANSK.
- O RUSSIANS DEMAND UNRESTRICTED PASSAGE OF NAVAL COMBATANTS THROUGH THE DARDANELLES.

FEBRUARY 15

- O RELIABLE U.S. NATIONAL SOURCES DETERMINE THAT AN UNUSUALLY HEAVY CONCENTRATION OF RAILROAD FREIGHT AND PASSENGER CARS ARE MARSHALLING ALONG MAIN RAIL ROUTES AND RAIL SIDINGS IN WESTERN MILITARY DISTRICTS OF USSR.

FEBRUARY 16

- O U.S. NAVY SHIPS IN PACIFIC AND ATLANTIC REPORT BEING TRAILED BY RUSSIAN VESSELS.
- O SOVIET COMMERCIAL FISHING FLEETS HAVE RETURNED TO THE USSR OR AT LEAST TO SOVIET WATERS.

FEBRUARY 17

- O RUSSIAN TRAWLERS THAT HAVE BEEN STATIONED ALONG U.S. SOUTHEAST COAST ARE REPORTED TO HAVE LEFT THE AREA.

FEBRUARY 18

- O RUSSIA DEMANDS DEMILITARIZATION OF THRACE.

Table B-8 – DATUM 4

DATA		PROBABILITY ASSESSMENT	
		PACT ATTACK	NO PACT ATTACK
INITIAL	THROUGH 1 FEB	.10	.90
DATUM 1	2 FEB - 4 FEB	.15	.85
DATUM 2	5 FEB - 9 FEB	.35	.65
DATUM 3	10 FEB - 13 FEB	.60	.40
DATUM 4	14 FEB - 18 FEB	.75	.25

Table B-9 — REVISED ASSESSMENT 4

FEBRUARY 19

- O RELIABLE BRITISH SOURCE REPORTS PACT AIR COMMANDERS MEETING IN WARSAW ALLEGEDLY TO FINALIZE EXERCISE RULES, A MEETING NOT OBSERVED IN PREVIOUS EXERCISES.
- O GDR AND CZECHOSLOVAKIA ANNOUNCE THAT IN THE INTERESTS OF SAFETY, THE BERLIN AND PRAGUE CORRIDORS WILL BE CLOSED TO ALL COMMERCIAL AIRCRAFT FROM 24 FEBRUARY THROUGH 21 MARCH. THEY ANNOUNCE THAT EVEN THOUGH THE CLOSURE STARTS PRIOR TO THE PLANNED START DATE OF THE EXERCISE, THE EXTENSIVE MOVEMENT OF MILITARY AIRCRAFT AND POSTURING FOR THE EXERCISE MAKE THE CURTAILMENT OF ALL COMMERCIAL FLIGHTS A NECESSITY.
- O THE BERLIN AUTHORITIES, POSTURING IMMEDIATELY, FILE A FORMAL PROTEST.

FEBRUARY 20

- O GDR ALLEGES TWO BORDER VIOLATIONS BY NATO AIRCRAFT.
- O TWO SOVIET MECHANIZED RIFLE DIVISIONS ARE REPORTED ENROUTE TO EXERCISE AREA FROM THE WESTERN MILITARY DISTRICTS OF USSR.
- O NATO NATIONS PROTEST AIR CORRIDOR CLOSINGS.

FEBRUARY 21

- O SOVIET GROUND FORCE UNITS DEPLOY TO EXERCISE ASSEMBLY AREAS.
- O GREATLY INCREASED COMMUNICATIONS AS WELL AS NEW SYSTEMS AND NETWORKS ARE NOTED.
- O HUNGARY ANNOUNCES THAT FOR ECONOMIC REASONS THE TWO DIVISIONS WHICH WERE PLANNED TO BE MOVED TO THE FORWARD EXERCISE AREA WILL PARTICIPATE IN PLACE.

FEBRUARY 22

- O THE GERMAN PERMANENT REPRESENTATIVE TO NATO HAS LEARNED FROM THE AUSTRIAN AMBASSADOR AT BONN THAT SERIOUS COMMUNIST-INSPIRED INCIDENTS, NEW CLANDESTINE RADIOS, AND TROOP ASSEMBLIES NEAR THEIR BORDER ARE OCCURRING.

Table B-10 — DATUM 5

FEBRUARY 23

O SHAPE INTELLIGENCE BELIEVES PACT NATIONS HAVE ACCOMPLISHED MANY ACTIONS NORMALLY INCLUDED IN GENERAL MOBILIZATION. AT LEAST ALL OF THE FRONT LINE AND REINFORCING DIVISIONS APPEAR TO BE FILLING TO 100%.

O GDR CLAIMS THREE BORDER VIOLATIONS BY WEST GERMANY AND STATES SHE IS BEING FORCED TO TAKE COUNTERMEASURES.

O MOSCOW ANNOUNCES ITS INTENT TO BRING A CAPITAL NAVY SHIP THROUGH THE DARDANELLES.

O RAIL AND ROAD TRAFFIC TO BERLIN IS SUBJECTED TO LONG DELAYS.

Table B-10 – DATUM 5 (continued)

AD-A035 386 DECISIONS AND DESIGNS INC MCLEAN VA F/G 5/1
RAPID SCREENING OF DECISION OPTIONS.(U)
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UNCLASSIFIED TR-76-12 NL

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DATA		PROBABILITY ASSESSMENT	
		PACT ATTACK	NO PACT ATTACK
INITIAL	THROUGH 1 FEB	.10	.90
DATUM 1	2 FEB - 4 FEB	.15	.85
DATUM 2	5 FEB - 9 FEB	.35	.65
DATUM 3	10 FEB - 13 FEB	.60	.40
DATUM 4	14 FEB - 18 FEB	.75	.25
DATUM 5	19 FEB - 23 FEB	.85	.15

Table B-11 – REVISED ASSESSMENT 5

FEBRUARY 24

- O U.S. REPORTS FAIRLY STRONG INDICATIONS THAT STORED W.P. MILITARY VEHICLES, RESERVE TANKS, AND WEAPONS HAVE BEEN READIED FOR USE.

- O SHAPE INTELLIGENCE IDENTIFIES 34 STANDBY AIRFIELDS IN POLAND, CZECHOSLOVAKIA, AND WESTERN USSR THAT ARE NOW CONSIDERED OPERATIONAL, AND ALL APPEAR TO BE UNDERGOING A RAPID LOGISTICS BUILD-UP.

- O GDR HALTS WESTERN ROAD AND RAIL TRAFFIC TO BERLIN WITH DETAILED, TIME-CONSUMING INSPECTIONS.

- O ALLIES CONTINUE HEAVY USE OF AIR CORRIDORS.

FEBRUARY 25

- O MOSCOW ANNOUNCES THAT ALL RUSSIAN PORTS WILL BE CLOSED TO FOREIGN SHIPS AND WILL REMAIN CLOSED UNTIL COMPLETION OF THE EXERCISE.

- O U.S. ANNOUNCES THAT ALL RUSSIAN MILITARY ATTACHES AND THEIR FAMILIES HAVE DEPARTED THE U.S. FOR MOSCOW.

FEBRUARY 26

- O MOSCOW NAVY SEIZES TWO DANISH COMMERCIAL SHIPS SOUTH OF SWEDISH ISLAND OF GOTLAND AND FORCES SHIPS TO DOCK IN PORT OF KALININGRAD.

- O WARSAW PACT AIR DEFENSE SYSTEM GOES ON MAXIMUM ALERT, ANNOUNCED AS THE FIRST LIVE PLAY IN PREPARATION FOR THE EXERCISE.

FEBRUARY 27

- O MOSCOW ANNOUNCES SUSPENSION OF ALL INTERNATIONAL AEROFLOT FLIGHTS UNTIL COMPLETION OF THE EXERCISE. AEROFLOT IS PLACED UNDER CONTROL OF THE MILITARY.

- O USSR VETOES U.S. SECURITY COUNCIL DISCUSSION OF DARDANELLES, THRACE, OR SEIZURE OF DANISH COMMERCIAL VESSELS.

Table B-12 – DATUM 6

MARCH 1

- O RUSSIAN MILITARY ATTACHES TO NATO NATIONS AND THEIR FAMILIES ARE CALLED HOME.
- O RUSSIA WARNS THAT THE AIR CORRIDOR TO BERLIN IS CLOSED FOR THE EXERCISE AND ANY COMMERCIAL OR MILITARY AIRCRAFT ATTEMPTING TO FLY TO BERLIN WILL BE FORCED TO LAND.

Table B-12 — DATUM 6 (continued)

DATA		PROBABILITY ASSESSMENT	
		PACT ATTACK	NO PACT ATTACK
INITIAL	THROUGH 1 FEB	.10	.90
DATUM 1	2 FEB - 4 FEB	.15	.85
DATUM 2	5 FEB - 9 FEB	.35	.65
DATUM 3	10 FEB - 13 FEB	.60	.40
DATUM 4	14 FEB - 18 FEB	.75	.25
DATUM 5	19 FEB - 23 FEB	.85	.15
DATUM 6	24 FEB - 1 MAR	.95	.05

Table B-13 — FINAL ASSESSMENT

The revision of the probabilities in the face of new data is important because it causes changes in the expected value of the regret associated with different decision options. The expected regret in turn is the criterion for deciding among the different options. Table B-14 shows the changes resulting from the new probabilities in the expected regret over time.

	1 Feb Initial	4 Feb Datum 1	9 Feb Datum 2	13 Feb Datum 3	18 Feb Datum 4	23 Feb Datum 5	1 Mar Datum 6
	Expected Value	Expected Value	Expected Value	Expected Value	Expected Value	Expected Value	Expected Value
MAINTAIN STATUS QUO	-9	-13	-31	-54	-67	-76	-85
MILITARY VIGILANCE	-12	-14	-20	-28	-33	-36	-39
SIMPLE ALERT	-22	-22	-21	-20	-20	-19	-19
REINFORCED ALERT	-37	-35	-29	-22	-17	-14	-11

Table B-14 — ANALYSIS OVER TIME

APPENDIX C

EXAMPLE: RAPID SCREENING PROCEDURE FOR A NAVAL EVACUATION OF CIVILIANS

Another hypothetical example of the use of the rapid screening procedure to analyze a problem of concern to military decision makers is in the context of a foreign civil war. The decision studied is what type of military naval preparedness should the U.S. maintain in the area if there were uncertainty about whether or not it will eventually become necessary to evacuate U.S. nationals and nationals of other friendly nations from the area. Suppose that the people concerned with this decision are members of Intelligence and Operations Staffs at the geographic area headquarters.

C.1 Structure of the Problem

After some discussion, the Operations participants in the study identify four options as being a summarized representation of the principal alternatives that they would decide among:

- Normal Fleet Operations. Normal operations posture would be maintained and no hedge would be made against the evacuation contingency other than keeping senior commanders informed of the general situation on a daily basis.

- Routine operations in area waters or ROP AREA posture. The fleet would conduct operations and training as usual except that those fleet units likely to participate in the evacuation would conduct their training in area waters until further notice.

- Modified location, or MOD LOC posture. Those fleet units designated to conduct an evacuation, if evacuation were to become necessary, would be maintained in close proximity to the country in order to reduce reaction time and to improve operational posture. (It was also believed that this posture and the visible U.S. presence might have a stabilizing influence on the general situation; however, this possible effect is not taken into account by the model.)

- Modified location and increased communications or COMMS posture is identical to the above evacuation capability except for an augmented communications capability that would give the National Command Authority a greater facility for directing and orchestrating the operation directly from Washington.

The uncertain event of importance in determining the best option, whose outcome would be unknown when the decision is made, is whether or not the U.S. would decide to evacuate some of its citizens and others from the country and, if so, how many would be evacuated and under what military conditions. In order to express this uncertainty as a single event with a limited number of outcomes, the whole spectrum of possible different evacuation numbers and conditions are approximated by five representative outcomes. The uncertain event is restated to be "Number evacuated with conditions of evacuation." The representative outcomes are: No evacuation, Permissive evacuation of 300 people, Permissive evacuation of 2000 people, Non-permissive evacuation of 2000 people, and Non-permissive evacuation of 6000 people. These are the outcomes whose probabilities must be assessed. The "Non-Permissive" condition means that the evacuation would be opposed by the combatants.

The important dimensions of value associated with different combinations of decision options with event outcomes are found to be:

- Exposure Risk: An assessment of the person-days of exposure to fighting suffered by the people to be evacuated. The exposure time begins with the executive order to evacuate and ends with the evacuation of all personnel.

- Readiness Cost: The additional dollar-related cost for fuel and maintenance of fleet units to maintain alert posture. Such costs are in addition to normal fleet operating costs.

- Flexibility Loss: Loss in combat readiness because of the evacuation alert posture would make it necessary for most naval units to reconfigure and relocate before performing assigned combat functions.

- Political Ramifications: An assessment of the national embarrassment or loss of prestige that would result if the U.S. failed to evacuate personnel safely or if the U.S. overreacted to the crisis and created an undesirable situation.

C.2 Inputs for the Problem

The assessment of the probabilities for the different outcomes is rather complicated because it turns out that the probabilities depend on a chain of other uncertain events. For example, the level of hostilities naturally has an effect on the number to be evacuated, but this level of hostilities

depends in part on an upcoming election, and so on. The procedure for taking these relationships into account, known as conditioned assessment, is explained in detail in Section 5.2 of this report. The probability values ultimately obtained for the different outcomes are shown in the computer printout of Figure C-1. (The probabilities are shown on a scale of zero to 100 rather than 0.00 to 1.00.)

Probabilities:

STATE* PROBABILITIES

NO	300 P	2K P	2K NP	6K NP
54	2	14	16	14

Values (Regret):

EXPOSURE RISK

	NO	300 P	2K P	2K NP	6K NP
NORMAL	0	¯10	¯30	¯100	¯100
ROP AREA	0	0	¯5	¯80	¯80
MOD LOC	¯1	0	0	¯5	¯10
+COMMS	¯1	0	0	0	0

READINESS COST

	NO	300 P	2K P	2K NP	6K NP
NORMAL	0	0	0	0	0
ROP AREA	¯30	¯30	¯30	¯30	¯30
MOD LOC	¯80	¯80	¯80	¯80	¯80
+COMMS	¯100	¯100	¯100	¯100	¯100

FLEXIBILITY LOSS

	NO	300 P	2K P	2K NP	6K NP
NORMAL	0	0	0	0	0
ROP AREA	¯40	¯40	¯40	¯40	¯40
MOD LOC	¯90	¯90	¯90	¯90	¯90
+COMMS	¯100	¯100	¯100	¯100	¯100

POLITICAL

	NO	300 P	2K P	2K NP	6K NP
NORMAL	0	¯40	¯60	¯100	¯100
ROP AREA	0	0	¯20	¯90	¯90
MOD LOC	¯5	0	0	¯20	¯20
+COMMS	¯10	0	0	0	0

Value Weights:

VALUE WEIGHTS

VALUE	WEIGHT
EXPOSURE RISK	43
READINESS COST	17
FLEXIBILITY LOSS	9
POLITICAL	30

*No = No Evacuation
300P = 300 People, Permissive
2KP = 2000 People, Permissive
2KNP = 2000 People, Non-Permissive
6KNP = 6000 People, Non-Permissive

Figure C-1

INPUTS TO THE CIVILIAN EVACUATION EXAMPLE: PROBABILITIES AND VALUES (REGRETS)

The assessment of the value, expressed in terms of regret, of the different option-outcomes combinations is relatively easy and follows the procedure outlined in Section 3.2.3. The resulting value matrices and the weights of the different dimensions are also shown in Figure C-1.

C.3 Output of the Analysis

The combined value matrix and the matrix of expected regret are shown in Figure C-2. The present values of the

COMBINED VALUE

	NO	300 P	2K P	2K NP	6K NP
NORMAL	0	¯17	¯31	¯74	¯74
ROP AREA	¯9	¯9	¯17	¯71	¯71
MOD LOC	¯24	¯22	¯22	¯30	¯32
+COMMS	¯30	¯26	¯26	¯26	¯26

EXPECTED VALUE

	NO	300 P	2K P	2K NP	6K NP	TOTAL
NORMAL	0	0	¯4	¯12	¯10	¯27
ROP AREA	¯5	0	¯2	¯11	¯10	¯29
MOD LOC	¯13	0	¯3	¯5	¯5	¯26
+COMMS	¯16	¯1	¯4	¯4	¯4	¯28

Figure C-2

OUTPUT OF THE ANALYSIS FOR THE CIVILIAN EVACUATION EXAMPLE: COMBINED VALUE MATRIX *AND EXPECTED VALUE MATRIX*

probabilities how that the optimal option is MOD LOC, to modify the location of some units of the fleet. The sensitivity of this decision to changes in the outcome probabilities is shown in the graph appearing as Figure C-3.

There is a line in the graph for each of the four decision options. The values of the line are the expected regret for the option at different probability levels. Since there are five different evacuation outcomes, the sensitivity analysis could look at changes in any two or more of these. (It is not possible to alter just a single outcome probability since all five probabilities must add up to 1.00.) In this example, the probability of no evacuation goes from 1.00 to 0.00, and, at the same time, the other four probabilities are altered so that their total goes from 0.00 (no evacuation) to 1.00 (some kind of evacuation for sure) and the relative likelihood (the ratio of these probabilities to each other) stays the same as in the original calculation. Preserving this constant relationship of relative likelihood causes the changing expected regret for a particular option to form a straight line as the probabilities vary.

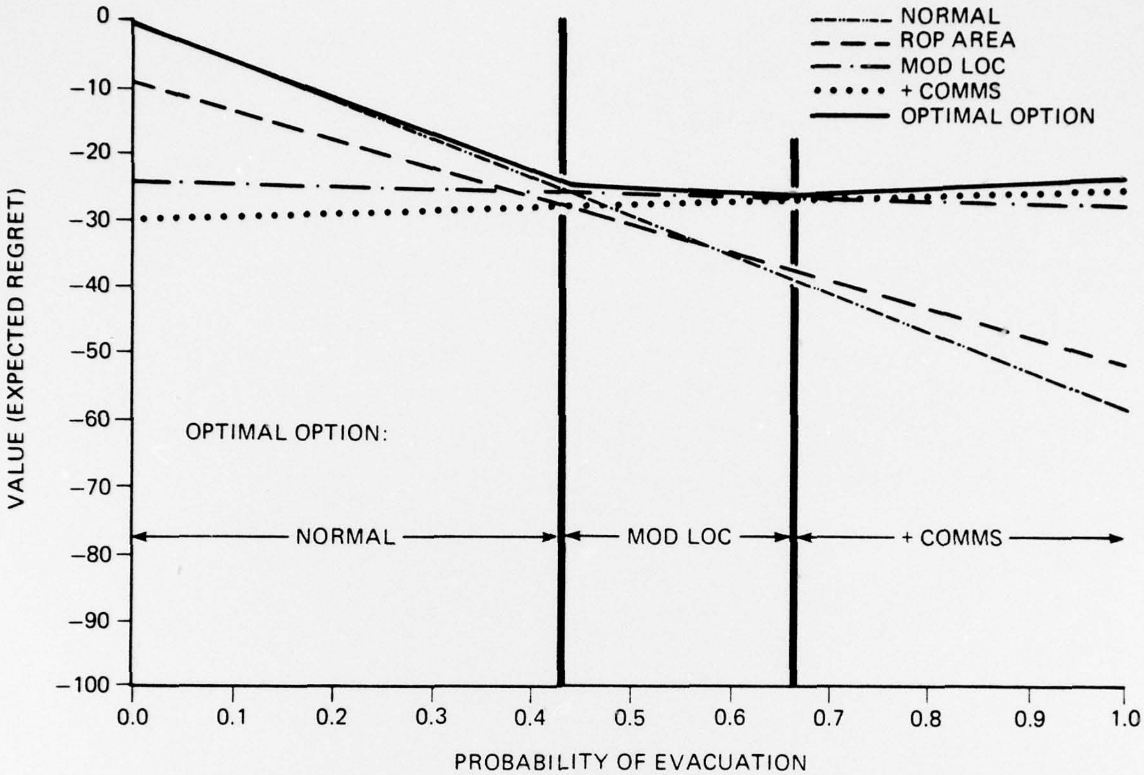

Figure C-3

CHANGES IN EXPECTED REGRET AS A FUNCTION OF CHANGING PROBABILITY OF EVACUATION

The graph makes an interesting revelation, namely, that one of the decision options, ROP AREA, is always dominated and so will never be chosen as the optimal decision (on the basis of the regret assessments used here) regardless of any changes in the probability assessment which preserve the original ratios among the evacuation outcomes. The graphic presentation also allows the decision maker to read off probability threshold values which show at what probability of evacuation versus no evacuation the optimal decision option changes. These probability changes are changes in the unconditional evacuation probabilities and say nothing about which of the secondary event probabilities (discussed in section 5.2) change in order to produce these new unconditional probabilities for the main uncertain event.

C.4 Discussion

If this rapid screening procedure were carried out with the military planners concerned about the problem illustrated here at the time a decision was pertinent, several advantages might result. The principal advantage of this decision aid would be that both groups of participants, intelligence and operations personnel, would develop a better understanding of the uncertainty inherent in estimates of the situation and the impact of those estimates on evacuation postures. The analysis would also afford the users a new rationale for examining evacuation postures, the results of which could be used to validate or question previous conclusions reached judgmentally on the basis of their previous experience. Acting officers, who are normally responsible for performing the detailed threat analysis and the posture formulations, could be helped to think through the problem and perform some "what-if" analysis. This improved understanding could extend to senior levels where both military (Joint Staff, JCS) and State Department officials are concerned with the decision making.

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